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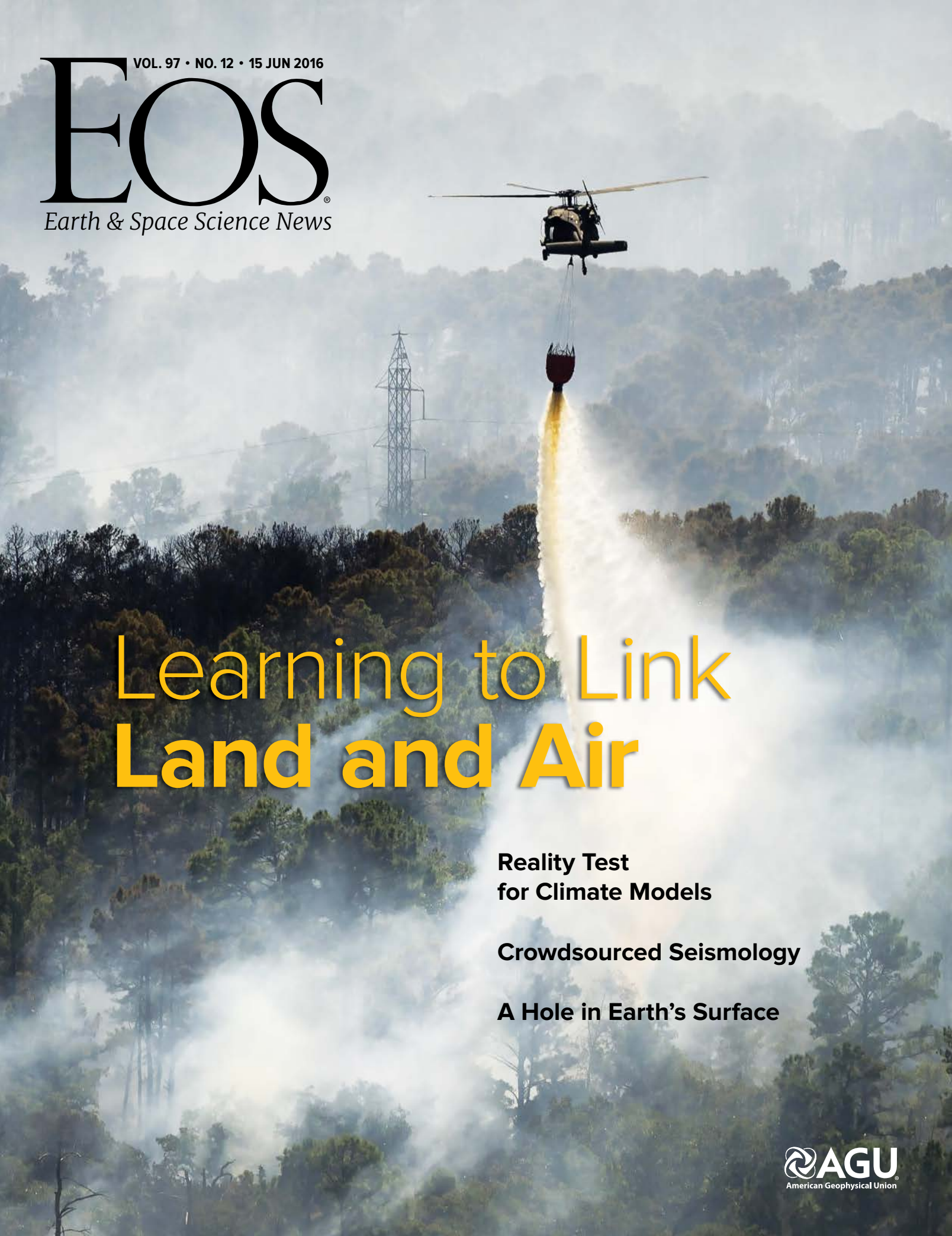
EOS

Earth & Space Science News



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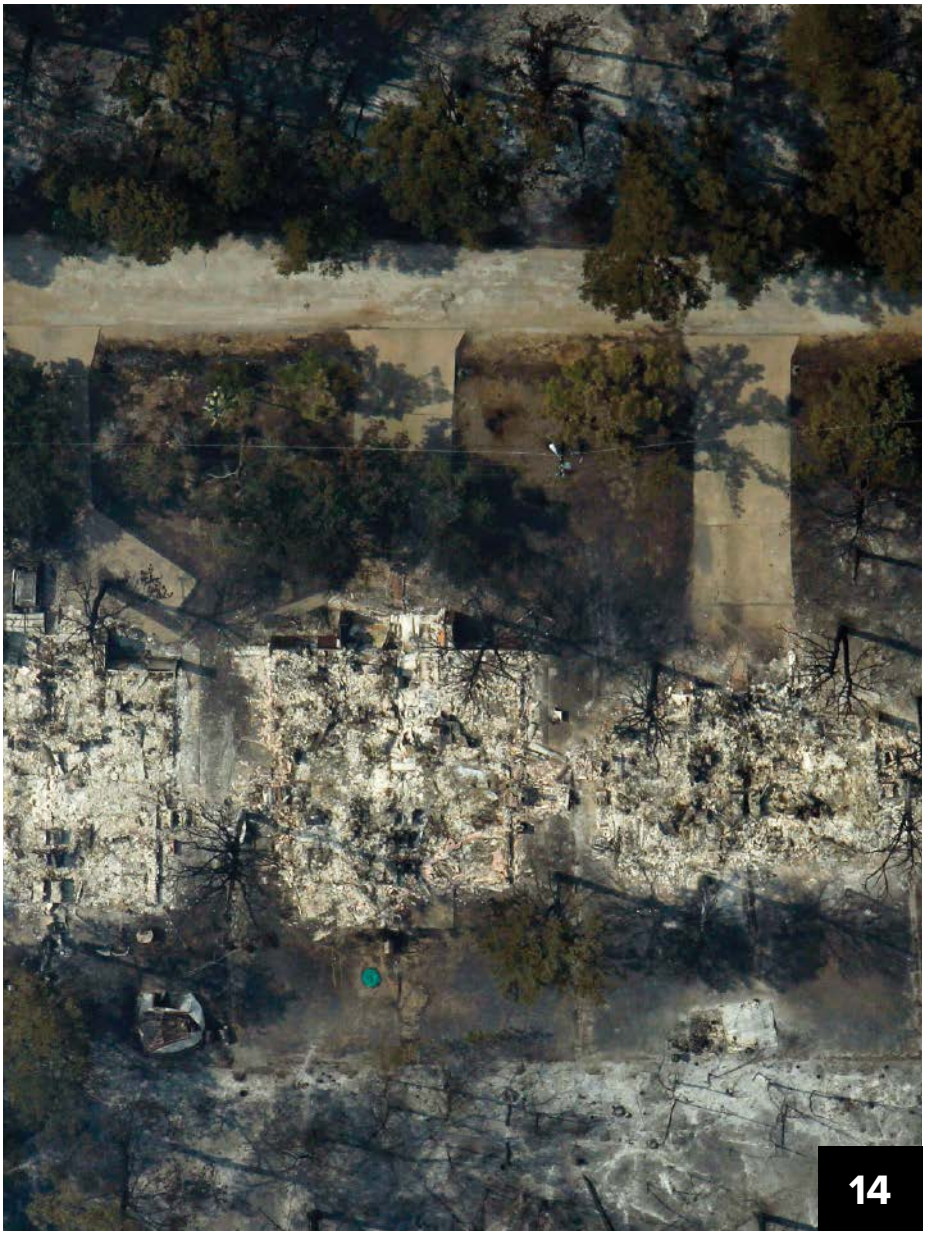

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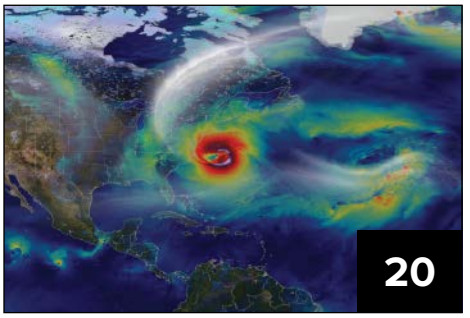

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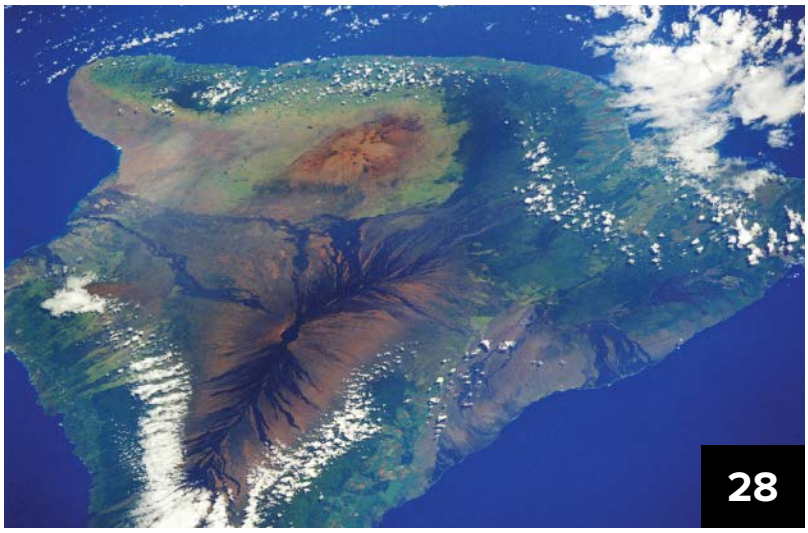

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Christine W. McEntee, Executive Director/CEO

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Undersea Data Tie Slow Fault Slip to Tsunami-Causing Quakes

Takeo Yagi, University of Tokyo

Scientists deploy an ocean bottom seismometer and absolute pressure gauge offshore of Gisborne, New Zealand, from the R/V Tangaroa.

Recent monitoring of the seafloor off the coast of New Zealand has revealed that episodes of slow rupture of Earth's crust can occur in the same shallow portion of a fault zone where tsunami-generating earthquakes originate. The new finding deepens scientists' suspicions that the type of slow-motion, or "silent," earthquake that the researchers detected, known as a slow-slip event, may signal or even trigger the onset of tsunami-generating earthquakes.

"There seems to be a link potentially with where these really shallow slow-slip events happen and where tsunami-generating earthquakes happen," said Laura Wallace, a research scientist at the University of Texas at Austin. Wallace is the lead author on a paper published last month in *Science* about the new observations (see http://bit.ly/NZ-slow-slip).

In undersea trenches in many parts of the world, one of the Earth's tectonic plates pushes beneath another, or subducts, in an inching, lurching process that builds up stress in the subduction zone that can catastrophically be released as an earthquake, which in turn can trigger a tsunami. However, in slow-slip events, which are common at subduction zones, sliding of the plates at a more rapid pace than usual (although still much slower than the sudden shift of an earthquake) relieves stress in the fault zone over a period of typically days to months.

In the new research published on 6 May, Wallace and her colleagues studied a subduction zone called the Hikurangi margin off the east coast of New Zealand's North Island, where the Pacific plate slowly slides under the Australian plate. In 1947, two earthquakes at shallow depths within this margin sent tsunamis crashing onto New Zealand's shore, damaging buildings and roads.

> "There seems to be a link potentially with where these really shallow slow-slip events happen and where tsunami-generating earthquakes happen."

Slowly Slipping Plate

Scientists have long tracked tectonic plate movements at subduction zones—for example, in Japan, Costa Rica, and the U.S. Pacific Northwest—by using land-based GPS monitors on the overlying plate that can detect motions deep below. However, gathering data on plate behavior at the relatively shallow undersea trench that lies offshore and is where the leading edge of the overlying plate meets the subducting plate has proven to be a difficult task requiring other sorts of sensors. GPS observations typically reveal slow-slip events in subduction zones at depths 25–50 kilometers below the trench, Wallace said.

Onshore near the Hikurangi margin, GPS measurements have shown that slow-slip events occur roughly every 18 months, the larger ones taking place once every 4–5 years, according to Wallace. To find out whether slow slip could be observed at shallow depths and offshore near the trench, she and her team picked a yearlong window of time when they would mostly likely detect a slow-slip event. Then, in May 2014, they deployed an array of 15 ocean bottom seismometers and 24 seafloor pressure gauges to record possible events.

Between May 2014 and June 2015, the pressure detectors revealed vertical movements of the ocean floor by, in essence, weighing the overlying water column: Higher pressure meant that the seafloor sank and more water pressed down, whereas a lower pressure indicated a rising seafloor, which displaced water and decreased the pressure.

After analyzing the data, the researchers found a slow-slip event that lasted 2 weeks and moved the seafloor upward 1.5–5.5 centimeters—a vertical movement associated with 15–20 centimeters of total slippage along the plate boundary. That shift equates to 3 to 4 years of normal plate movement, Wallace said.

The recently revealed slow-slip rupture took place in the same shallow portion of the subduction zone where the 1947 tsunami-generating earthquakes had originated. If this slip had occurred suddenly rather than over the course of 2 weeks, it would have clocked in

as a magnitude 6.8 earthquake, the researchers report.

"Our results clearly show that shallow, slow-slip event source areas are also capable of hosting seismic rupture and generating tsunamis," said Yoshihiro Ito of Kyoto University in Japan, who coauthored the study.

Future Earthquake Monitoring

Earlier this year, another *Science* paper reported that slow-slip events often occurred before an earthquake of magnitude 5 or higher hit. In fact, a swarm of slow-slip events preceded the devastating 9.0 magnitude earthquake and tsunami that hit Japan in 2011 (see http://bit.ly/subtle-seismic).

Scientists have typically detected slow slip at subduction zones at tens of kilometers beneath the trench, where temperatures reach 350°C–450°C and pressures are high, Wallace said. They suspected that slow-slip events also occurred in shallower regions of trenches, less than 10–15 kilometers deep, where pressures and temperatures are lower and tsunami-generating earthquakes originate.

The new findings indicate that slow-slip events can indeed happen "over a massive range of conditions," from warm temperatures and high pressures within the crust to shallow locations, cooler crustal temperatures, and lower pressures, Wallace continued. "This is important to know because we don't really understand yet why these slow-slip events happen." She added that slow-slip events might trigger earthquakes in a subduction zone by providing stress relief in one area that causes stress buildup somewhere else, leading to a sudden rupture.

"These data should aid in better understanding these somewhat enigmatic shallow tsunami earthquakes," said Roland Burgmann, a seismologist at University of California, Berkeley, who wasn't involved in the research.

Wallace and her colleagues plan to investigate the Hikurangi margin in the future by drilling into the seafloor to figure out what causes slow-slip events in the first place.

Having now observed slow slip close to the epicenter of the 1947 earthquake underscores the need for monitoring, Wallace said, "because there's potential for a slow-slip event to trigger an earthquake that could generate a big tsunami."

By **JoAnna Wendel,** Staff Writer

Editor's Note: For a detailed look at research efforts off New Zealand's coast that led to the results described above, visit http://bit.ly/shallow-slow-slip.

Gypsum Forms in an Unexpected Way

Alexander E. S. van Driessche

Gypsum selenite crystals on a matrix of alabaster from Quinto de Ebro, Zaragoza, Spain. Museo Geominero, Madrid, Spain. Gypsum's formation has been found to begin with the assembly of previously unknown "nanobricks."

Gypsum, a common and economically important mineral that occurs on Earth's surface, has long been thought by scientists to grow simply from the right ions meeting up in a liquid solution. But experiments by a team of European researchers show that gypsum, which is the main ingredient in plaster wallboard used in construction throughout the world, forms by means of a much more complex process than that.

Gypsum, it seems, gets made not in one step but in a series of four distinct stages, starting with the self-assembly of submicroscopic cylindrical particles the experimenters call "nanobricks." By manipulating this four-stage process, the experimenters said, manufacturers may one day make the annual production of billions of kilograms of plaster of paris—and thus the manufacturing of wallboard—far more energy efficient than current methods permit.

The new work may have otherworldly implications as well, the researchers said: It might yield new insights into the evolution of the surface of Mars.

"I think the most important highlight…is that gypsum grows from nanobricks rather than from simple ions dissolved in solution," said Tomasz Stawski, a geochemist with the University of Leeds in the United Kingdom as well as the German Research Centre for Geosciences in Germany and lead author of the recent *Nature Communications* paper (http://bit.ly/gypsum-nanobricks). "It seems that [the nanobricks] form immediately in solution, and then the entire process is driven by the interaction of those nanobricks…with each other," he said.

"Stem Cell" Building Blocks

Stawski and his colleagues achieved their novel insights into gypsum formation by using X-ray beams produced by the Diamond Light Source synchrotron in Harwell, U.K., to observe the process as it unfolded. Because gypsum is a type of calcium sulfate, the researchers first mixed in a glass reactor an aqueous solution rich in calcium chloride and another rich in sodium sulfate to bring together the ingredients necessary to make the basic compound. Then, circulating the mixed solutions through a much smaller chamber for observation, the team fired X-ray beams "head-on through the sample," Stawski said, and studied the ways those beams scattered off of building blocks of gypsum as they formed in the liquid.

"Think about the sunset," Stawski said. "When you start seeing red colors in the sky, it is due to the scattering of sunlight at very small angles when it hits dust particles in the air." Similarly, he explained, when X-rays strike newly formed structures in the solution, the beams deflect in specific directions based on the unique arrangement of the atoms composing those structures. The scattering patterns, interpreted with the help of a mathematical model, allowed the scientists "to extrapolate how large those [precursors of gypsum] are, or what their shape is," Stawski said. "Everything has a structure, and scattering methods are fantastic [for] accessing this hidden information."

The four stages of the pathway unfolded as follows, according to Stawski. First, nanobricks about 3 nanometers in length and 1 nanometer in diameter formed. Then the bricks clustered into loose groups, or "domains"—a very important development, Stawski said, "because the chances that the bricks will meet each other increase," leading to mineral precipitation.

In the third stage, "there is a triggering moment during which all the nanobricks come together, and this is what we see as precipitation, but at this stage there is still no gypsum." Finally comes the fourth stage: Within the structures that formed in stage 3, "the nanobricks begin to reassemble, maybe to grow in size—we're not exactly sure—and only in this stage does gypsum form," Stawski noted.

"What this group has done is figure out how to use light sources in order to probe all of these early events and get information that is very difficult to get any other way," said Jim De Yoreo, a materials scientist at Pacific Northwest National Laboratory in Richland, Wash., and the University of Washington in Seattle, who was not involved in the new work. "They have done what I think is an incredible job in using a modern tool to track down and scoop out this pathway."

De Yoreo compared the nanobricks loosely to stem cells, which can ultimately turn into a variety of different tissues in the body. Like stem cells, the nanobricks will not necessarily go on to form only gypsum: They can also lead to other calcium sulfate minerals like bassanite and anhydrite, depending on the conditions under which mineral formation takes place. Which mineral you get depends on how much water permeates the mineral structure. Whereas a minuscule single crystal of gypsum harbors two water molecules, two bassanite crystals share just one water molecule. Anhydrite crystals contain no water molecules.

Depending on the "physiochemical conditions—such as very high salinity, higher temperatures, or rapid quenching—the reaction reported in our paper can lead to bassanite or anhydrite instead of gypsum," said Stawski. Prior to these new experiments, it was thought that dehydrating gypsum, or causing it to lose its water molecules, was the only way of forming a phase like bassanite, the key ingredient in plaster of paris.

Chip Clark

A specimen of the mineral gypsum exhibits sinuous crystal growth. Gypsum (R 13219), National Mineral Collection, Smithsonian Institution.

Industrial Applications and Water on Mars

Knowing what's really going on in gypsum formation could eventually help curb the voracious energy consumption of the construction industry, the research team reports in its 1 April paper. Each year humanity produces about 100 billion kilograms of plaster of paris by heating gypsum to about 150°C to remove the water molecules, the experimenters note. "It is superinefficient—it's a very energy-intensive process, and you need to remove the water to get bassanite," which, Stawski said, is dehydrated gypsum—plaster of paris's primary ingredient.

By manipulating the four-stage formation pathway, it might be possible to produce plaster of paris without using so much energy, he explained: "If you take gypsum and put it into water and dissolve it, [you can] get the nanobricks again," he said. Then, instead of doing all that heating, "we need simply force the nanobricks to rearrange themselves into bassanite rather than gypsum, by controlling the chemistry."

An extraterrestrial consequence of the new findings might even await. That's because understanding calcium sulfate minerals' formation pathway might help us better understand the evolution of the surface of a sister planet—Mars—the scientists propose. Whereas bassanite can occasionally be found on Earth, "it's not very common because the moment it gets any moisture it converts into gypsum," said Stawski. "But it's very abundant on Mars, [and] the question is, How does it form there?"

"If it formed by the dehydration of gypsum, that will tell us something about the [early] conditions on Mars," where, if gypsum was once present, then there may also have been more water there than exists today. Alternatively, if rearranging nanobricks can also form bassanite, then Martian bassanite may not have formed simply by drying out, added Stawski.

For all the light that Stawski and his colleagues have now shed on gypsum's formation, a lot about the four-stage pathway still remains to be discovered, said De Yoreo, who calls the four-stage pathway "a solid concept seen through very foggy glasses."

"It's an advance in that we can say, 'yes, there are these objects, and we can track the time scale over which this happens,'" he explained. However, exactly how does each stage transform into the next? he asked. That's still a mystery.

By **Lucas Joel,** Freelance Writer; e-mail: lucasvjoel@gmail.com

Climate Cooling from Icy Clouds May Fall Short of Expectations

Larissa Lacher

A wave of mixed-phase clouds composed of ice and supercooled liquid water brushes the peaks of Jungfraujoch in the Swiss Alps. Wispy cloud layers indicate the presence of ice crystals. Puffy cloud layers contain a larger fraction of liquid droplets that reflect sunlight more effectively than ice does.

Cloud science matters to many climatologists almost as much as it does to meteorologists. Depending on clouds' altitudes and compositions, those vaporous puffs can influence global temperatures enough that climate scientists include them in their predictive models.

A recent study published in *Science* reveals, however, that most models underestimate how much cooling the planet receives now from clouds that contain both water droplets and ice crystals (see http://bit.ly/mpc-paper). Moreover, the chilling impact of those clouds may diminish as atmospheric greenhouse gas concentrations increase.

Clouds Respond to Carbon Dioxide

Although anyone can observe clouds simply by looking at the sky, these important atmospheric features have proven difficult to study scientifically, especially when it comes to mixed-phase clouds. These clouds, prevalent at higher latitudes, drift across the skies in the upper reaches of the Earth's troposphere, where the air temperature ranges from about 0°C to -40°C. Unlike clouds in lower, warmer layers of the atmosphere, which contain only liquid water droplets, high-altitude mixed-phase clouds contain water as supercooled liquid droplets mixed with some ice fragments. The ratio of water to ice can vary depending on the cloud—and because the cloud's behavior depends on a set of complex interactions between melting ice and freezing water, the effects of these interactions can be difficult to predict and study on a large scale.

This unpredictability has important implications for climate change because mixed-phase clouds have been a climate mystery for many years. Clouds can have either a cooling or a warming effect on the planet, depending on their altitude and composition: Low-lying, watery clouds block sunlight for a mild cooling effect, whereas higher-altitude icy clouds, including mixed-phase clouds, let in more sunlight. Because scientists weren't sure of the exact mix of water and ice in mixed-phase clouds, their effect on climate was difficult to determine.

What's more, unlike already liquid clouds at lower altitudes, mixed-phase clouds' composition will likely change as their layer of the atmosphere heats up. "The entire troposphere deepens with global warming," explained Ivy Tan, one of the authors of the new study. As the troposphere creeps upward, the rising warmth should melt some of the ice in clouds. When that happens, "regions with clouds once dominated with ice now predominantly contain liquid," Tan said.

The shift to more liquid makes the clouds denser, more opaque, and better at reflecting the Sun's radiation. However, cloud researchers could only estimate how much this transition in cloud composition would act as a brake on climate warming because they had only a general idea of how much of the water in mixed-phase clouds was frozen.

CALIPSO's Unclouded Vision

To get a better picture of these mixed-phase clouds, the research team, composed of Ivy Tan and Trude Storelvmo of Yale University in New Haven, Conn., and Mark Zelinka of Lawrence Livermore National Laboratory in Livermore, Calif., looked at data from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), a NASA satellite that uses lidar to observe clouds from above. By shining a laser down into the clouds, the satellite was able to determine whether any given spot in a cloud was made of water, ice, or air. Its polar orbit allows the satellite to get much more data on cloud composition over the entire planet than ground-based lidar systems, which typically send laser beams up from a fixed point or vehicle. After analyzing more than 6 years' worth of data, the team of scientists found that mixed-phase clouds were much more liquid, and less icy, than previous estimates had suggested—their study brought the estimated fraction of liquid water in the cloud from 20% to around 60%.

The findings, published on 8 April, could have a big impact on what we know about Earth's future: Because mixed-phase clouds have less ice in them to begin with than most scientists originally thought, their potential for becoming denser is also less than previously predicted. This diminished potential means that clouds are much less effective as a buffer against global warming than climatologists have assumed.

With all these new data taken into account, Tan said, the team's climate model yields considerably higher estimates than it previously did for how much global temperature will rise because of greenhouse gas emissions. In a scenario in which the concentration of atmospheric carbon dioxide doubles, the team's model had predicted a global temperature rise of 2.0°C to 4.6°C, which agreed with most climatologists' expectations. With the revised impact prediction for mixed-phase clouds, the model's estimates increase by as much as 1.3°C, Tan and her colleagues report.

Another Piece in the Climate Puzzle

The new study has "made a simple and persuasive point demonstrating the importance of the mixed-phase cloud feedback in the Earth system," Daniel McCoy, an atmospheric scientist at the University of Washington in Seattle, commented in an email. McCoy was not involved in the study.

Some scientists remain unconvinced that the team's new projections for global temperature increase are on the mark. Emphasizing that mixed-phase clouds are just one element of a dynamic climate system, Gavin Schmidt, director of NASA's Goddard Institute for Space Studies in New York, N.Y., who was not involved with the study, urged in an email that the new cloud data should be tested with other constraints and other models. "This is one extra ingredient that needs to go into the hopper," he wrote.

By **Elizabeth Deatrick,** Writer Intern

Chilly Reception for New Australian Climate Science Center

Bruce Miller

The proposed new Climate Science Centre would coordinate the Australian government's remaining basic climate measurements and modeling, including its program of Argo ocean floats (shown).

Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) has created a new climate science division, a move many scientists said wouldn't fully undo the damage of previously announced research cuts. As the nation's premiere scientific agency, CSIRO sparked controversy months ago by revealing plans for a shift in its research focus away from basic climate science and toward climate change response strategies.

The announcement of the new research unit, CSIRO leaders said, served in part as a response to widespread criticism from scientists—including some in-house—over the proposed shift in focus. Critics had argued that CSIRO's previously disclosed plans to cut roughly half of its 140 climate science staffers would imperil the agency's ability to carry out the basic climate modeling and measurement projects that it had hoped to keep.

But CSIRO leaders say the new Climate Science Centre—staffed by 40, overseen by an independent advisory board, and armed with a decade-long commitment from the agency—will help coordinate and preserve those modeling and measurement projects. And agency officials said they planned to cut 25 to 30 fewer climate science staff across CSIRO than before (see http://bit.ly/CSIRO-CSC).

Long-Simmering Controversy

Still, many Australian scientists are unmoved, saying the center's meager staffing level renders it a mostly toothless face-saving effort. "While the retention of some of CSIRO's climate science capabilities is welcome, the level announced is analogous to trying to put a sticking plaster over a gaping wound," sustainability researcher Dave Griggs of Monash University in Melbourne said in a 26 April statement.

The controversy traces back to February, when CSIRO told staff of its proposed cuts, likely followed by new hires in other areas. CSIRO leaders, wanting to shift focus toward climate change mitigation and adaptation, argued that Australia needed economically innovative research to stay globally competitive. Scientists and scientific organizations across the world called the plans a blow to Australia's scientific reputation and argued against the research shift because scientists still have much to learn about the climate system.

Now, with the proposed new division, scientists are expressing some relief. And Liberal Party senator Richard Colbeck, who already supported CSIRO's research refocusing, lauded the creation of the center and the advisory board, which he said would advise Prime Minister Malcolm Turnbull's Liberal-National coalition government. However, scientists still worry that CSIRO will struggle to keep its promise of maintaining key basic climate research projects, among them the Cape Grim greenhouse gas monitoring station and the Argo ocean floats.

New Center Too Small?

In statements compiled by the Australian Science Media Centre, many climate scientists said the center needs more than 40 staffers. Similar centers in other countries have several times more, according to Matthew England, a climate researcher at the University of New South Wales based in the Sydney area (see http://bit.ly/CSIRO-center-Feedback).

Australian senator Peter Whish-Wilson of the Australian Greens party cited these scientists' statements in noting his own skepticism of the plan. "Clearly the reaction…was that the number is too low and that this was more or less reshuffling the deck chairs," he said on 27 April at a live webcast Australian Senate budget panel hearing.

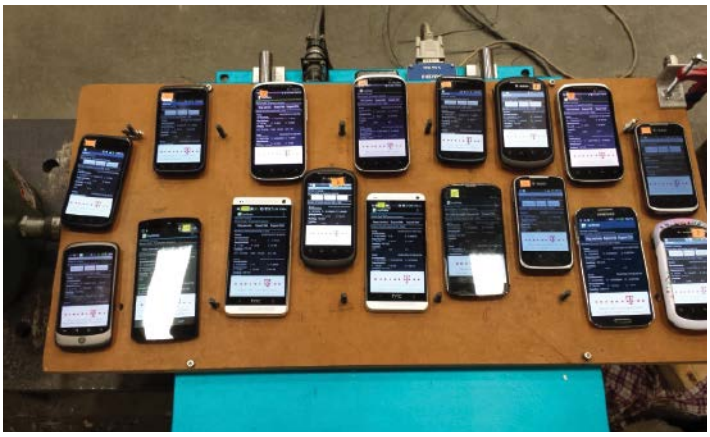
CSIRO chief executive Larry Marshall responded that recent research budget cuts have forced tough choices at the agency. "Any chief executive would always want more money to do more," he said at the hearing.

Marshall added that CSIRO created the center with feedback from staffers as well as external scientists and universities. Having a body to oversee key agency climate projects and giving it an advisory board will help coordinate the research and promote external collaboration, he said.

Steven Sherwood, a climate researcher at the University of New South Wales, looked favorably on the prospect of more coordination and the advisory board, even as he criticized its staffing level. "Both of these would be positive developments, but the small size of the new centre would limit what it could achieve for Australia," he said in a statement.

By **Puneet Kollipara,** Freelance Writer; email: puneet.kollipara@gmail.com

Crowdsourced Seismology



Berkeley Seismological Laboratory

In tests of the MyShake app, researchers subjected cell phones to simulated earthquakes using a shake table at the University of California, Berkeley.

At the Seismological Society of America (SSA) meeting this spring, in a session on "Citizen Seismology," researchers from around the globe presented their crowdsourced earthquake detection networks.

From cell phone apps to sensors in basements, these projects recruit ordinary people to gather and report data on nearby earthquakes. They generate dense networks of sensors while also teaching their citizen volunteers about earthquakes.

Made possible by the advent of the Internet and smartphones, this distributed way of gathering data can sometimes make up for shortfalls of traditional precision seismograph networks, seismologists said. For instance, citizen science networks can sometimes outpace traditional earthquake monitoring networks in reporting to a central database and may form denser networks than the conventional ones, enabling seismologists to more quickly triangulate an earthquake's epicenter. What's more, they can capture the actual impact of an earthquake on people's lives, U.S. Geological Survey (USGS) analyst Vincent Quitoriano, who works on a quake detection website called "Did You Feel It?," told *Eos*.

Because these novel quake monitoring projects engage volunteers and turn them into a larger scientific workforce, "there's more education happening, there's more research happening. People are just more involved in their communities," Danielle Sumy, a seismologist with the Incorporated Research Institutions for Seismology in Washington, D. C., told *Eos*. She works on the California-based Quake-Catcher Network project.

Each project has its own scope, focus, and means of detecting earthquakes; here are five of them:

1 MyShake. This app for Android phones relies on the phone's internal sensor to detect ongoing quakes. Place the phone on a flat surface, leave it alone for half an hour to calibrate, and it will begin "listening" for tremors that disturb the phone's built-in accelerometer. Anything that fits the profile of an earthquake gets automatically reported to the MyShake database. The MyShake team at the University of California, Berkeley, hopes eventually to build a global network of MyShake users and to produce an iPhone version of the app (see http://bit.ly/My-Shake).

2 LastQuake. Like MyShake, LastQuake is an app for smartphones—but this one relies on volunteer reporting rather than on the phone's internal hardware. The LastQuake system, created by a team at the European-Mediterranean Seismological Centre in Essonne, France, sifts through Internet traffic on Twitter and other public networks, looking for reports of tremors. Users located near earthquake epicenters can fill out a questionnaire to rank the earthquake's intensity (see http://bit.ly/Last-Q).

3 AcceleROB. Not all earthquake crowdsourcing requires a smartphone: Across Belgium, in quiet garages and basements, a network of cheap, boxy sensors attached to bricks is listening for tremors. The AcceleROB program, run by the Royal Observatory of Belgium in Brussels, has asked volunteers to host its cheap, low-power, Internet-connected accelerometers in their homes. So far, only 28 households across Belgium have done so, but the program hopes to send out 70 more sensors, allowing its team to monitor the whole country (see http://bit.ly/A-R-B).

4 Quake-Catcher Network. This project works much like AcceleROB but on a global scale: Teachers and other hosts can ask for a sensor that can be taped to the floor and plugged into a computer by means of a USB cable. The sensor then constantly monitors tremors, broadcasting any disturbance back to the project leaders at the California-based Quake-Catcher Network (QCN). The project also has an educational component: The project leads are trying to get more schools involved, distributing lesson plans on the QCN website (see http://bit.ly/Q-C-N).

5 Did You Feel It? The USGS has its own earthquake-watching project that gets its input from questionnaires. For 20 years, users anywhere in the world have been able to fill out an online form when they feel a quake, answering such questions as "Did you notice any swinging of doors or other free-hanging objects?" The program takes the answers and aggregates them with other local reports to assign an intensity to the quake. The team is currently building a prototype system of volunteer reporting that they hope will be able to gather earthquake location and intensity data faster than traditional seismograph networks (see http://bit.ly/Did-You_Feel_It).

For most of these projects, seismologists seemed encouraged by the responsiveness of citizen scientists. "For a very large earthquake, we'll get around 20,000–30,000 responses in the U.S.," Quitoriano told *Eos*. "For smaller earthquakes, we'll get on the order of 5000–6000."

Seismological research has benefited from these new data sources. For instance, during a 24 January, 7.1 magnitude Alaskan earthquake (see http://bit.ly/alaskan-quake), seismometers tuned to monitor lower-magnitude tremors became oversaturated by the quake's intensity. "But some of the USB sensors that we had in schools were able to get really accurate recordings," said Sumy. "So they've proved very useful in environments where other sensors that might not be on the right scale have failed."

At the SSA meeting, which took place in Reno, Nev., in late April, the different groups were able to meet and share their data. Some of the researchers have said they hope to interconnect citizen science networks with traditional instruments to collect data from both simultaneously, which should result in more quickly available and accurate online earthquake maps. "In the future, we're hoping to have a convergence of data streams," said Quitoriano. "There's still some work to be done, but I can see that that's the direction we're heading in."

By **Elizabeth Deatrick,** Writer Intern

U.S. Arctic Leader: Shell Oil Pullout Reduced Beneficial Focus on Arctic

REUTERS/Jason Redmond

Shell Oil had used the Polar Pioneer rig during a drilling campaign off Alaska before deciding last fall to cease offshore exploration activities in the Arctic.

Royal Dutch Shell's September 2015 decision to cease oil exploration activity offshore of Alaska has lessened global awareness of Arctic issues, said the U.S. special representative for the polar region in a recent talk in Washington, D. C. "I am discouraged that Shell is not going to be drilling up there in the near future," Admiral Robert Papp Jr. (retired) told a 25 April forum at the Brookings Institution, a policy think tank (see http://bit.ly/Admrl-Papp-talk).

The oil company's activity "was visible, something that really drew a lot of attention [and] which provided that sense of urgency to act," Papp said. Shell's activities had put Arctic issues, including climate change, preventing oil spills, and balancing environmental protection and resource development, in the spotlight.

In an interview with *Eos*, Papp also expressed concern about keeping attention on the Arctic following the U.S. presidential election and during a new administration with its own priorities. "Making sure we have continuity [on Arctic issues] and get[ing] the new team up to speed as quickly as possible" rank as probably his highest priority as U.S. special representative for the Arctic, Papp told *Eos*.

Brookings billed Papp's talk as a status report on U.S. leadership in the Arctic at the midpoint of the United States' 2-year chairmanship of the Arctic Council, an intergovernmental forum of eight Arctic nations. Member countries rotate through 2-year stints chairing the body.

> Papp described a "sense of urgency" at the White House "that progress has to be made now in advancing our Arctic priorities."

Papp cited progress in the first year of the U.S. chairmanship on Arctic issues, including raising awareness of the region among Americans outside of Alaska. He noted that U.S. president Barack Obama, who spent 3 days in Alaska last summer, "is personally engaged in Arctic issues" and has focused on the effect of climate change in the Arctic. Papp described a "sense of urgency" at the White House "that progress has to be made now in advancing our Arctic priorities."

"We must address the impacts of climate change," Papp added. "There may be no issues with greater long-term consequences for the Arctic." He said the council "is looking at what a 2°C temperature increase would look like for the Arctic" to prepare for warming effects and push resilience efforts.

Initiatives Include Scientific Cooperation and Arctic Infrastructure

The United States chairs the council until May 2017. Papp said that before the term ends, the council might finalize a legally binding agreement on scientific cooperation in the Arctic region (see http://bit.ly/Arctic-pact). It's also working on a circumpolar infrastructure assessment with recommendations for Arctic states to ramp up telecommunications capacity to support navigation, offshore development, and improved responses to environmental and humanitarian emergencies.

Arctic Council member states also recently provided reports to the council on black carbon, or soot—a global atmospheric pollutant and major contributor to climate change. Among other effects, black carbon darkens snow and ice, increasing energy absorption and melting.

Another council project cited by Papp, an online map of circumpolar renewable energy resources, could help Arctic communities reduce costs and greenhouse gases. Papp added that the United States will lead discussions on Arctic marine cooperation and a regional seas agreement.

Oil Concerns Continue

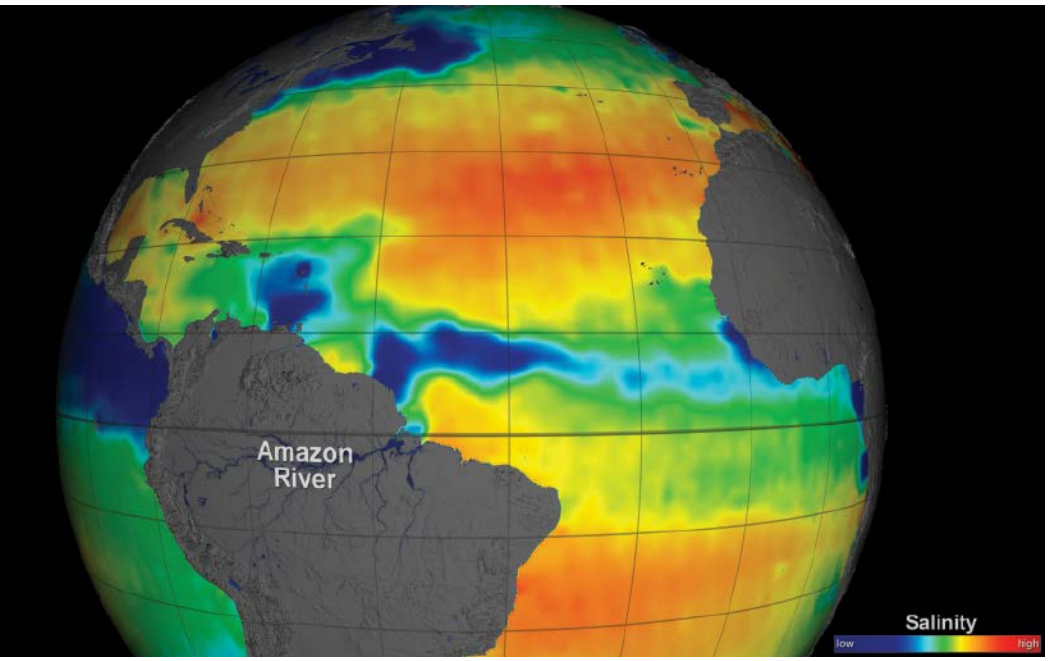
Papp said the Arctic Council's 2013 oil spill preparedness agreement came into effect earlier this year, and he hopes a full-scale exercise will take place soon. He emphasized that despite Shell's decision to cease its offshore drilling, oil spill prevention remains a high concern.

"The reality is that there are ships passing through the Bering Strait each and every day carrying fuel," he said. A ship leak may not cause as much damage as a blown-out oil well, he said, but any oil spill is "particularly bad in the Arctic."

By **Randy Showstack,** Staff Writer

Salinity Monitoring Gives Insight into the Global Water Cycle

Salinity and Water Cycle over the Oceans: Recent Progress and Future Challenges
Hamburg, Germany, 12–15 October 2015



Data from NASA's Aquarius instrument reveal seasonal changes in the Amazon River's plume. (This map shows conditions on 27 February 2013. Red indicates high salinity, and blue indicates low salinity.) Depending on the prevailing currents, the river's freshwater outflow heads east toward Africa or bends north toward the Caribbean. Salinity variations are one of the main drivers of ocean circulation.

The global water cycle is one of the fundamental elements of the Earth's climate system, involving the exchange of freshwater within the entire ocean–land–atmosphere system. Predicting changes in this cycle over the next decades and beyond provides critical information to societies for making decisions on water management, agriculture, and other factors.

The ocean is the world's largest reservoir of water, providing more than 75% of Earth's evaporated and precipitated water. Thus, to successfully predict the future of the global water cycle, we need to understand the changes in transport of freshwater in the ocean. Studying these changes requires investigating changes in salinity, the primary indicator of regional changes of freshwater in the ocean.

A workshop (see http://bit.ly/salinity-workshop) held at the Center for Earth System Research and Sustainability (Universität Hamburg, Germany) reviewed recent progress on salinity and freshwater research and included discussions of problems that must be solved to improve our understanding of future changes in the water cycle.

The workshop brought together nearly 100 scientists from around the world. Their results emphasized the importance of salinity changes to changes in the density field of the ocean, which influences a wide range of processes affecting ocean dynamics, including sea level height, interocean water exchange, propagation of planetary and tropical instability waves, and mesoscale variability in ocean fronts and eddies.

Existing observations of salinity changes provide strong evidence for changes in the ocean water cycle over recent decades.

At the workshop, advances in understanding the ocean's water cycle, made possible by innovations in the salinity observing system that recently began providing near-instantaneous snapshots of the global salinity field, were reported. These advances include the near-global three-dimensional sampling by the Argo array of temperature and salinity profiling floats (see http://www.argo.ucsd.edu) and space-borne measurements of sea surface salinity using the European Space Agency's Soil Moisture and Ocean Salinity spacecraft (SMOS; see http://bit.ly/SMOS-spacecraft) and NASA's Aquarius mission aboard the Argentine SAC-D spacecraft (which ceased operations in June 2015; see http://aquarius.nasa.gov).

A major recommendation of the workshop is to maintain data streams from surface and satellite observing systems. This includes maintaining the Argo array, continuing salinity satellite missions, and, especially, expanding satellite constellations to observe the entire global hydrological cycle, including processes over the ocean, in the cryosphere, on land, and in the atmosphere.

Existing observations of salinity changes provide strong evidence for changes in the ocean water cycle over recent decades. Climate projections suggest that those changes will further amplify in a warming world. The next challenge is to reconcile available information over land and over the ocean and to strengthen the link between efforts concerning the oceanic and terrestrial components of the global hydrological cycle. Providing better estimates of precipitation over the ocean is a step in this direction.

This workshop was sponsored by the Deutsche Forschungsgemeinschaft–funded research effort FOR1740 on salinity changes and by the European Space Agency, NASA, and the National Oceanic and Atmospheric Administration. It was endorsed by Climate and Ocean: Variability, Predictability and Change (CLIVAR), US CLIVAR, and the Global Energy and Water Cycle Exchanges Project (GEWEX).

By **Detlef Stammer,** Center for Earth System Research and Sustainability, Universität Hamburg, Hamburg, Germany; email: detlef.stammer@uni-hamburg.de

Paleofires and Models Illuminate Future Fire Scenarios

Advances in Interdisciplinary Paleofire Research: Data and Model Comparisons for the Past Millennium
Harvard Forest, Petersham, Massachusetts, 27 September to 2 October 2015

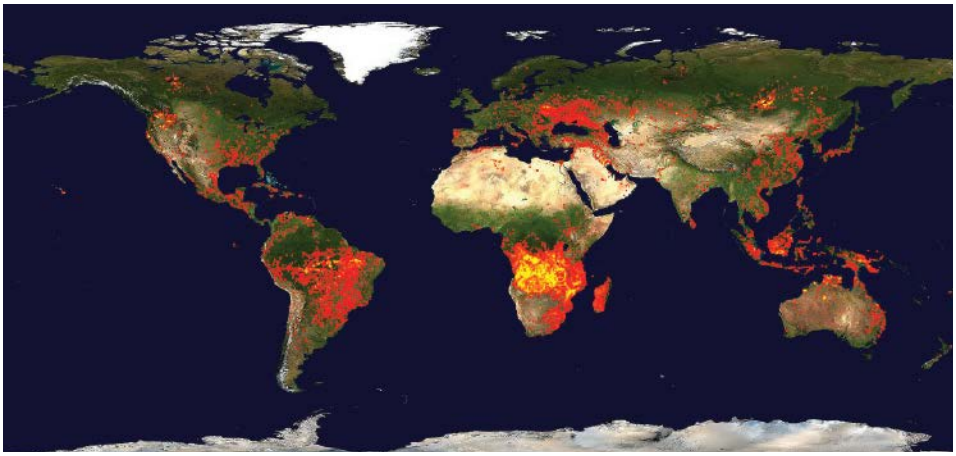
Fire regimes are shaped by biological, physical, and climatic processes that operate across decadal, centennial, and millennial timescales. These regimes have been modified by human land use for millennia. Thus, setting realistic restoration goals for forest management and conservation requires a historical baseline of fire under more "natural" conditions.

Regional to global syntheses of biomass burning through the Global Charcoal Database (see http://www.paleofire.org) initiative show complex interactions between climate, vegetation, and fire. This complexity implies that the ways that fire regimes change in response to forecasted climatic changes may be difficult to predict, particularly across ecosystem and climatic boundaries.

Last fall, the Global Paleofire Working Group (GPWG), an international group of researchers who study fires recorded in the sedimentary record via charcoal particles, gathered to discuss technical and conceptual challenges in reconstructing paleofires, new statistical approaches for reducing uncertainties in data and models, and interdisciplinary analyses of fire data from multiple archives (lake sediment, tree rings, and ice cores). These analyses rely on information from the Global Charcoal Database, GPWG's innovative database that uses multiple preserved physical records (proxies) that stand in for direct measurements of events in the distant past. Discussions focused on diverse topics, such as fire-vegetation interactions and the mechanisms governing extreme fire events (see http://bit.ly/paleofiremtg).

Fire-vegetation feedbacks (in which vegetation fuels fires, and fires assist some types of vegetation) are important determinants of biome distributions, but their role in mediating vegetation changes, as observed in the paleorecord, is poorly understood. Workshop participants designed an interdisciplinary approach combining modeling techniques with paleodata (e.g., pollen and sediment charcoal) that will test the role of fire feedbacks in fire-prone ecosystems during past biome transitions.

Understanding determinants of severe fire events in the past is relevant for managing ecosystems in the future. A subgroup therefore designed a model-data approach to test whether the use of fire by ancient North Americans—for example, for hunting and harvesting—changed across regions and during key cultural phases. Past changes in fires during cultural transitions can therefore inform today's managers about the impacts of altered fire regimes on vegetation dynamics and the relative roles of climate and humans in shaping fire-affected landscapes.



NASA/EOSDIS, FIRMS

Red and yellow dots indicate fire activity observed by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) in fall 2010. Paleofire records can provide information about natural fire regimes before land use intensification and the extent to which humans shaped present ecosystems and modern fire regimes.

Workshop attendees also identified data-model comparisons that will help researchers assess the climatic controls over "megafires." Researchers' efforts to combine models and data at different spatial and temporal scales will require filling gaps in key areas where charcoal data are presently scarce, such as Africa and Eurasia, which is now a top priority for the GPWG.

To address the scarcity of calibration studies in many areas of the world, attendees developed both empirical and process-based approaches to relate quantitative charcoal measurements to physical fire regime properties. For example, modern surface samples coupled with satellite data of known areas of burning (see map) will help constrain source areas of charcoal and link them to the distribution of charcoal particles across landscapes so that scientists can learn about the processes that control where charcoal particles actually end up. Meanwhile, young researchers will lead a project—one of many interdisciplinary efforts that emerged from discussions at the workshop—to refine data collection protocols to allow data comparisons at global scales.

Workshop attendees agreed that future studies must emphasize data calibration, modeling, and new proxies to tackle long-standing challenges for paleofire researchers, such as refining the timing and extent of anthropogenic fire across ecosystems and biomes. The GPWG will continue to strengthen interdisciplinary approaches and foster cooperation between researchers, land managers, and stakeholders interested in the climatic, land use, and biodiversity impacts of fire. As the Global Charcoal Database grows beyond its current 700 records, new analyses and integrative data-model studies will become possible.

GPWG (see http://www.gpwg.paleofire.org) is supported by the U.S. National Science Foundation (NSF) and the Swiss National Science Foundation through Past Global Changes (PAGES). NSF grant BCS-1437074 supported the workshop.

By **Ann Robertson,** Yale Program on Climate Change Communication, Yale University, New Haven, Conn.; email: ann.robertson@yale.edu; **Esther Githumbi,** York Institute for Tropical Ecosystems, Environment Department, University of York, Heslington, York, U.K.; and **Daniele Colombaroli,** Oeschger Centre for Climate Change Research and Institute of Plant Sciences, University of Bern, Bern, Switzerland

Diversifying Skills and Promoting Teamwork in Science

Pixabay (public domain)

Hiring and promoting academic research scientists based on a wide variety of skills and how their individual skills complement the team encourage these scientists to excel in the tasks in which their talents lie.

Increasing diversity in science is an important and widely recognized goal: Significant effort has gone into recruiting a broad spectrum of demographic groups to the field. However, one aspect of scientific diversity is largely overlooked, in part because of the excessive use of a few quantitative metrics in assessing research performance. Here we examine this issue in the context of the academic science community.

We argue that widespread assessment based on a few quantitative metrics has substantially reduced the diversity of skills and teamwork in science. A further depletion of diverse personalities and undervalued skills may seriously impair innovativeness and will favor research along established pathways rather than transformative outside-of-the-box science.

Some scientists are good at acquiring grant money, others are good at communicating research to peers, and still others are good at teaching or outreach activities. Using a single, limited set of metrics (for example, grant money and number of scientific publications) to assess the suitability of candidates across these types of scientists is unreasonable.

If the hiring and promotion strategy of scientific institutions changes so that candidates are selected on the basis of how their individual skills complement the team, scientists will be allowed—and even have an incentive—to excel in the tasks where their talents lie.

Mainstream Metrics Lead to Mainstream Science

For governments and organizations that decide on scientific priorities and funding, the ability to assess the performance of individual scientists, institutions, and entire nations is vital. For example, academic scientists' performance is now commonly evaluated using quantitative metrics such as the *h*-index for measuring their publications' impact, the number of publications, or acquired grant money [*Weingart*, 2005; *Kaushal and Jeschke*, 2013; *Arlinghaus*, 2014]. As a consequence, scientists and heads of institutions adapt their behaviors and strategies to optimize their performance according to such metrics.

It is important to realize that current metrics represent only a fraction of the key responsibilities of scientists. The widespread use of these quantitative metrics can lead to the selection and promotion of a uniform type of scientist.

Institutions differ in the way they assess scientists, but the quantitative metrics that many use for hiring and promotion decisions focus on acquiring grant money, performing research, and communicating research to peers. Teaching, mentoring, engaging with the public, in-depth reviewing of manuscripts and grant proposals, and serving on panels of experts usually do not factor strongly in performance evaluation metrics [*Arlinghaus*, 2014]. Although these tasks play a key role in helping our scientific system to function and many institutions ask for evidence that researchers "have done their share," scientists' performance in these areas is rarely important for hiring and promotion decisions.

One Size Does Not Fit All

Also, researchers are typically assessed by individual-level metrics, whereas their contributions as members of research *teams* are not explicitly considered and valued. Bright scientists with skills not represented by current metrics or whose contributions as team players are overlooked might easily become frustrated and leave science, joining public and private organizations where their skills and contributions are more highly valued.

Successful sports managers and hiring managers at leading companies carefully select team members on the basis of how their individual skills complement those already present in a team. A possible path forward to promote intellectual diversity in scientific institutions is to recognize that one size (i.e., one skill set or personality type) does *not* fit all.

We suggest that scientific institutions reward teamwork, which recognizes the need to look for complementary skills in candidates. To be successful in the long term, team members must exhibit a variety of skills beyond a common foundation of basic skills.

Building on Individual Strengths

Even the most accomplished scientists have uneven skills, allowing them to excel in some tasks but not in others. For example, Charles Darwin had outstanding skills in performing research and communicating research to peers. However, Darwin was independently wealthy and could pursue his research interests without developing the skills to acquire long-term grants [*Loehle*, 1990].

A short list of the basic skills needed by an academic research scientist includes

- acquiring grant money
- performing research
- communicating research to peers: writing scientific publications, presenting results at scientific conferences, etc.
- serving as an expert: service in the scientific institution (e.g., administrative service, serving on faculty panels) and service in the wider scientific community (e.g., reviewing

manuscripts and grant proposals, editorial work, serving on scientific committees)

- engaging with the public (outreach): discussing research results with public stakeholders, serving as a consultant, etc. [*Pace et al.*, 2010]
- mentoring
- teaching

Each individual scientist has a unique mix of strengths and weaknesses in these areas. Fostering individual areas of strength promotes diversity in science, whereas selecting a limited set of skills reduces scientific diversity.

Building Diverse Teams

We argue that scientific institutions should better recognize the value of diversity of individual characters, skills, and positions, and they should also better value the potential for teamwork [*Weingart*, 2005; *Arlinghaus*, 2014]. Although scientists often view themselves as leaders of research teams, we are also part of broader teams—departments, universities, and academic communities.

More specifically, we propose that hiring committees should better value the diverse types of scientists that an academic institution needs to achieve an optimal mix of staff scientists and to promote overall performance. A look beyond academia might be helpful in this regard, as successful sports clubs and leading companies have much experience in hiring individuals that complement the team and promote teamwork.

> Assessment based on a few quantitative metrics has substantially reduced the diversity of skills and teamwork in science.

Building teams that consist of diverse types of scientists will promote intellectual diversity. Also, research has shown that diverse teams often outperform homogeneous groups, even homogeneous groups of high-performing individuals [*Hong and Page*, 2004]. The promotion of intellectually diverse teams can thus create synergies and accelerate scientific progress—it can make the whole greater than the sum of the parts.

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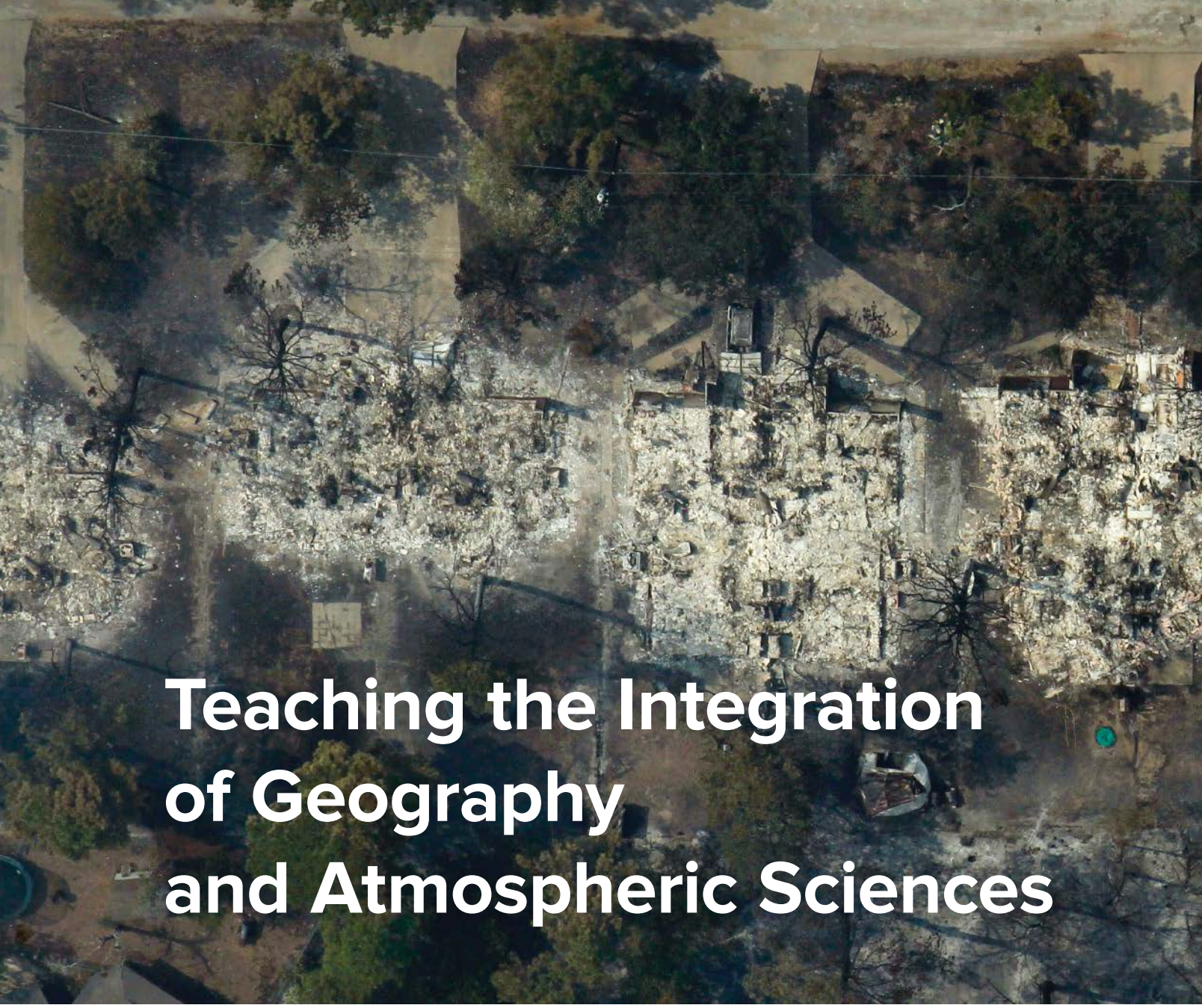


Teaching the Integration of Geography and Atmospheric Sciences

Atmospheric scientists spent a decade incorporating geographic information systems into their research and operations. Now it is time to incorporate GIS into atmospheric science education.

By Jennifer Boehnert, J. Greg Dobson, and Olga Wilhelmi

Erich Schlegel/Stringer/Getty Images

In September 2011, wildfire destroyed houses in this residential subdivision in Bastrop, Texas. Global information systems (GIS) can help atmospheric scientists put such incidents into a broader geophysical context.

Significant effort has gone into making atmospheric data sets, including weather and climate records, more compatible with existing geographic information systems (GIS) software platforms over the past 10 years, and these platforms have evolved to better incorporate atmospheric data sets. However, the atmospheric science community still needs to get better at training atmospheric students and scientists how to use GIS tools, and we need to make weather and climate model results more accessible to scientists, emergency managers, and policy makers who already rely on GIS for mapping and analysis tools.

GIS excels at integrating multiple, diverse data sets to provide a picture of how atmospheric phenomena affect society and the environment. The integration of weather and climate data with socioeconomic, environmental, and infrastructure data can help to answer interdisciplinary questions about population vulnerability to dangerous weather events like extreme heat [*Uejio et al.*, 2011], flash flooding [*Wilhelmi and Morss*, 2012], and hurricanes [*Taramelli et al.*, 2015].

What Is GIS?

Many definitions of GIS are floating around. *Bolstad* [2005, p. 1] states that GIS "is a tool for making and using spatial information." More specifically, GIS is defined as a

computer-based system to collect, store, analyze, and distribute spatial data.

Real-world objects, such as buildings, roads, and land use types, are represented as points, lines, and polygons on a map. By mapping multiple real-world objects together on one map, we can better understand the relationships, patterns, and trends of these features. GIS has been used over the past 45 years in such areas as land management, forestry, and city planning [*Miller et al.*, 2015].

Using GIS as an analysis tool for atmospheric data sets fosters research collaborations across geoscience disciplines, and GIS tools can make weather and climate data more usable and accessible to nonatmospheric scientists. This cross-fertilization benefits scientists, practitioners, and educators from both the atmospheric sciences and the geography disciplinary domains [*Wilhelmi and Brunskill*, 2003, p. 1411].

History of GIS Integration with Weather and Climate

In the past, the lack of interoperability between atmospheric data sets and GIS tools was a barrier to interdisciplinary research [*Wilhelmi and Betancourt*, 2005]. Bridging atmospheric sciences and GIS domains required interoperability between the data sets and the analysis tools.

Interoperability experiments initially focused on reformatting data so they could be used in the ArcGIS software [*Wilhelmi and Betancourt*, 2005, p. 177]. To integrate GIS data sets, primarily base map information, with weather model output, such as Fifth-Generation Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) output, GIS data sets had to be converted to the Web Map Services (WMS) standard protocol or images. By using open geospatial standards, GIS data could be visualized as an overlay with atmospheric data in atmospheric sciences tools, such as Cartesian Interactive Data Display (CIDD).

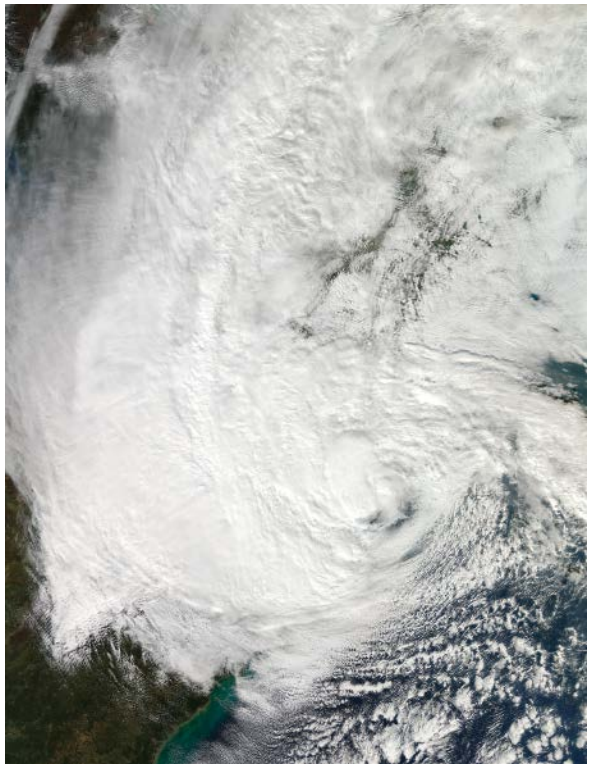
In 2006, Esri, the GIS software company that produces ArcGIS, developed the capability to read a common atmospheric data format, called Network Common Data Form (netCDF), and integrated it into their desktop application. This new capability, incorporated into ArcGIS 9.2, came about as a result of a multiyear collaboration across industry, government, and academia led by the NCAR GIS Program.

When ArcGIS 9.2 was released, a more straightforward technological connection between atmospheric and geospatial domains was established. This new functionality opened the door for incorporating weather and climate data with traditional GIS data sets to map, analyze, and query data from different disciplines in one seamless application. For example, you could examine the ways that mountains affect temperature and precipitation by creating a visualization that combined a terrain map with data on temperature and precipitation patterns.

The new capability for ArcGIS to read the netCDF data format enabled researchers and decision makers who are familiar with the GIS technology to better understand the spatial dimension of weather and climate phenomena and to conduct such interdisciplinary projects as vulnerability and impact assessments for climate change and extreme weather events [*Armstrong et al.*, 2015].

Another recent advancement is the increasing availability of weather and climate data sets in GIS-friendly formats. The ability to read traditional atmospheric data in GIS and the availability of weather and climate information in traditional GIS formats have been essential for the interoperability of these two disciplines.

National Weather Service weather warning polygons are available in shapefile format, a traditional GIS data type. The availability of these data in a GIS-friendly format enables emergency managers to see who and what may be affected by the extreme weather [*Waters et al.*, 2005]. Reverse 9-1-1 operators can identify and contact households within the warning area through standard GIS overlay methods and tools [*Cutter*, 2003].



Jeff Schmaltz, NASA GSFC

Satellite image of Hurricane Sandy on 29 October 2012. Exercise 3 of the "GIS Tutorial for Atmospheric Sciences" lab tutorial uses Sandy as an example of creating maps that communicate the effects of major weather events.

GIS Tutorial for Atmospheric Sciences

Fast-forward 10 years, and a lack of educational materials still presents a barrier to integrating GIS with the atmospheric sciences. Only a small number of atmospheric or Earth sciences departments in U.S. universities and colleges currently teach or require a GIS course. Even fewer offer any courses that integrate weather and climate applications and data with GIS tools and methods.

The lack of open-access curricula that bridge these domains is still apparent. Students seeking degrees in the atmospheric sciences need curricula on how to integrate atmospheric sciences with GIS tools and methods, but meteorologists, climatologists, and other atmospheric science professionals can also benefit from learning how

to use GIS data and tools in research and operations. Esri recently published a collection of advanced-use cases of how GIS is being used to map and model weather and climate [*Armstrong et al.*, 2015]. However, this book is not meant as a hands-on learning resource, and it does not cover the fundamental GIS skills that beginners need to get started.

To address this problem, the NCAR GIS Program has collaborated with the University of North Carolina at Asheville's National Environmental Modeling and Analysis Center to develop the first hands-on open-access GIS lab tutorial, the "GIS Tutorial for Atmospheric Sciences" (http://bit.ly/GIS-Atmo-Tutorial). Many free online general GIS courses are available; learning GIS through relevant weather and climate applications is what makes this tutorial novel.

All of these exercises use data that are freely available on the Web, and they teach the introductory capabilities of GIS. The GIS concepts and methods included in this course use ArcGIS Desktop, but they are transferable to other GIS software platforms.

Section 1 of this tutorial, which consists of five hands-on exercises, has recently been released and made available online. These first exercises cover the introductory concepts and methods necessary to understand how to work with spatial data in a GIS environment.

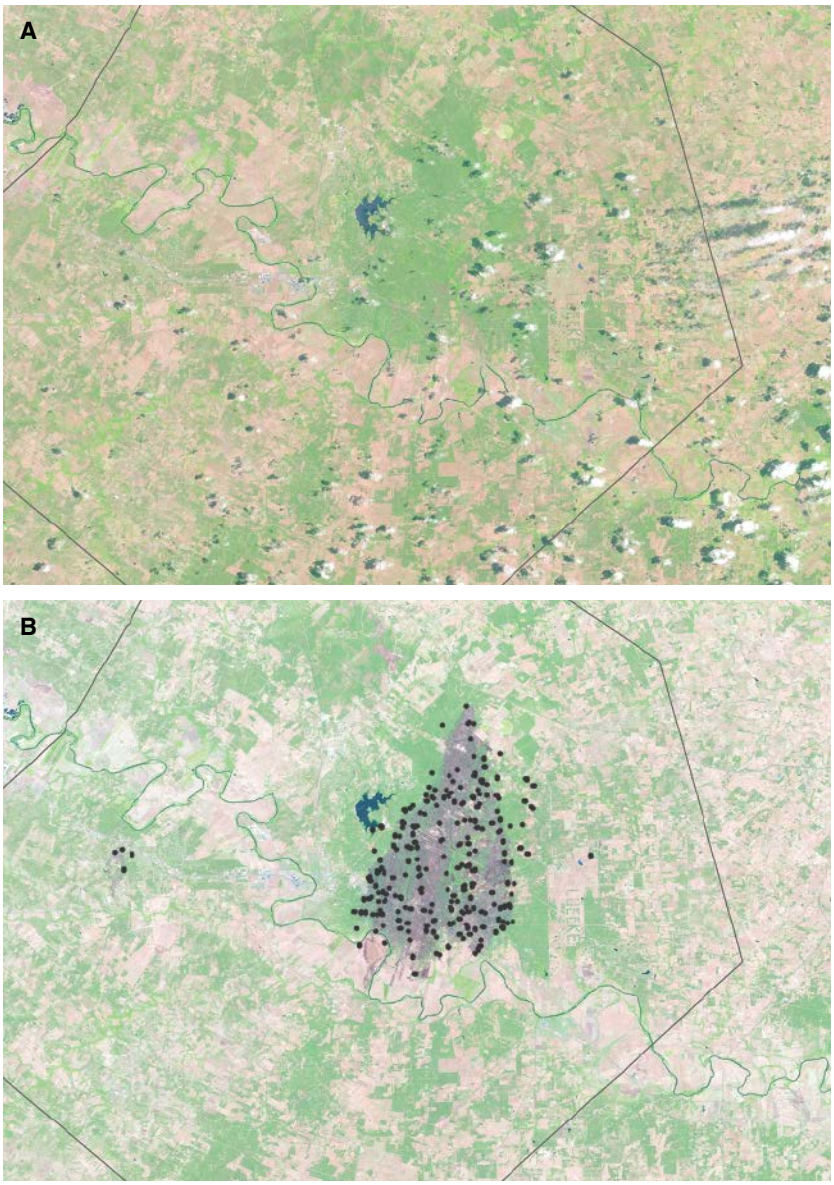


Fig. 1. Integration of remote sensing products in a geographic information system (GIS): (a) Landsat imagery of Bastrop County, Texas, from 9 July 2011; (b) Landsat imagery of the Bastrop County Complex Fire burn scar as observed on 11 September 2011. Black dots indicate fire locations as detected by the Moderate Resolution Imaging Spectroradiometer (MODIS) during the summer of 2011.

GIS Basics in Five Exercises

In Exercise 1, "Exploring ArcMap and ArcCatalog," we use observed tornado track data to map where tornado activity has occurred in the past. This module combines historical tornado track information from the National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center with a state boundary GIS data set to identify where most tornadoes have occurred over the past 50 years.

Exercise 2, "Exploring Spatial Data," explores the 2012 drought in Texas and highlights the ability of GIS tools to combine several spatial data sets in one application. Figure 1 illustrates how satellite imagery from different sources can be used to analyze wildfires in a GIS framework. This exercise integrates data from the U.S. Drought Monitor, station-based meteorological data, Landsat remote sensing observations, Moderate Resolution Imaging Spectroradiometer (MODIS) fire locations, and land use data sets to better understand how drought affects wildfires.

Exercise 3, "Data Symbology and Classification," analyzes the official track for Hurricane Sandy, along with the Federal Emergency Management Agency's Impacts Database. The combination of these two data sets allows students to create a map that helps to better communicate the impacts from Hurricane Sandy.

Exercise 4, "Cartographic Mapping," uses NOAA Cooperative Observer Network data to map the 1993 blizzard, often called the Superstorm, that dumped record snow

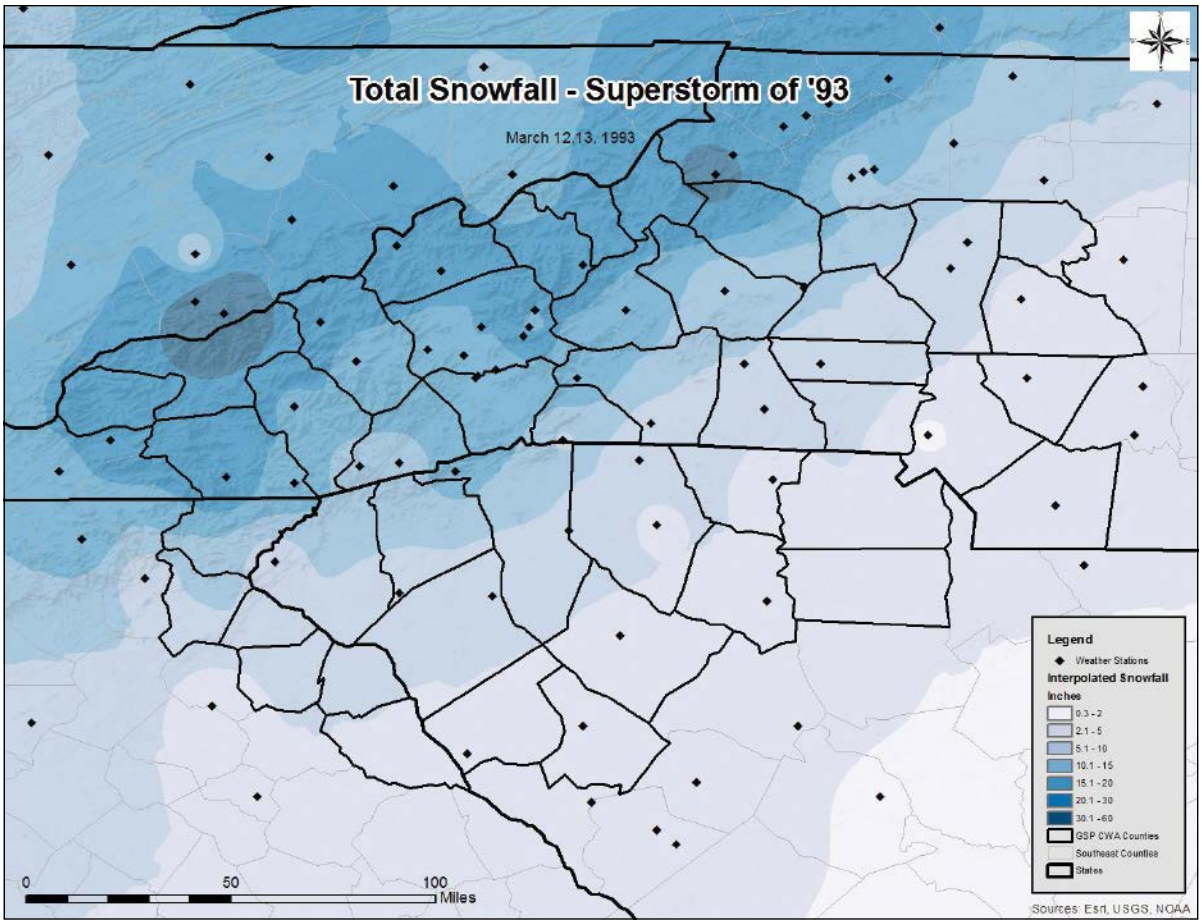


Fig. 2. Final map product of the snowfall totals observed from the Superstorm of 1993, created in Exercise 4 of the "GIS Tutorial for Atmospheric Sciences" lab tutorial.

falls over much of the East Coast of the United States. An illustration of this mapping exercise in shown in Figure 2.

Finally, Exercise 5, "Coordinate Systems and Map Projections," explores map projections and datum concepts using climate model simulation output provided by NOAA and the U.S. Global Change Research Program.

Future Work

This year, the "GIS Tutorial for Atmospheric Sciences" will be expanded to include additional exercises that focus on intermediate and advanced topics in GIS. This new section will teach students about working with netCDF in ArcMap, analysis and geoprocessing tools, Web mapping, and animation of data through time. In addition, we plan to develop a version of the tutorial that will be based on the Quantum GIS (QGIS) open-source GIS platform. Feedback from students, educators, researchers, and practitioners will guide the development of new hands-on exercises that integrate atmospheric sciences with GIS tools and methods.

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AGU LEADER

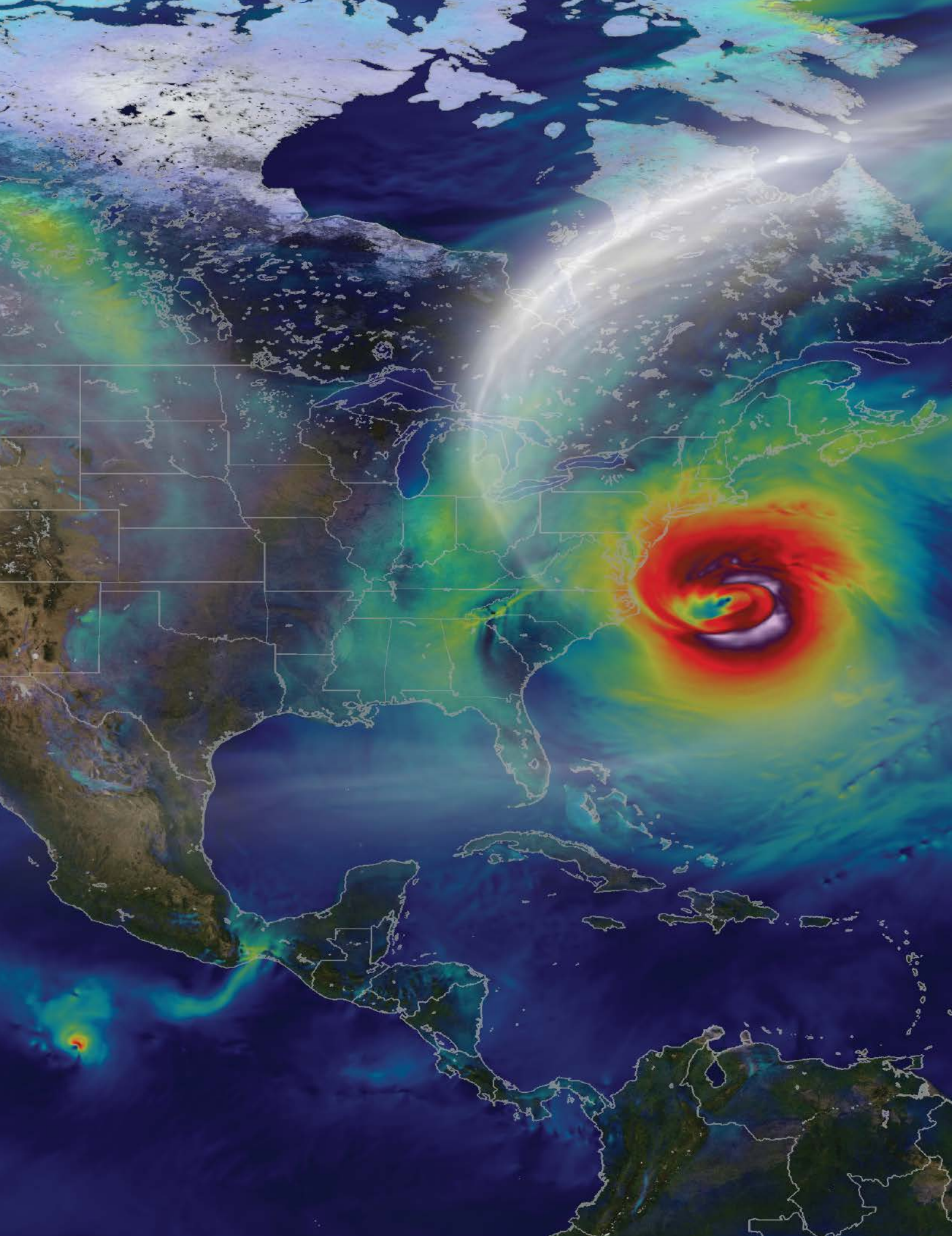
2016 ELECTIONS

Voting is a member benefit that influences the direction of AGU.

Plan to vote starting 29 August.

- **Now Online:** Full slate of leadership candidates for review; petition for additional nominations must be received by 6 June
- **1 August:** AGU membership and section/focus group affiliations need to be current to be eligible to vote
- **29 August:** Polls open
- **27 September:** Polls close

elections.agu.org



A More Powerful Reality Test for Climate Models

By Peter J. Gleckler, Charles Doutriaux, Paul J. Durack, Karl E. Taylor, Yuying Zhang, Dean N. Williams, Erik Mason, and Jérôme Servonnat

Projections of climate change are based on theory, historical data, and results from physically based climate models. Building confidence in climate models and their projections involves quantitative comparisons of simulations with a diverse suite of observations. Climate modelers often consider information from well-established tests and comparisons among existing models to help decide on a new model version among multiple candidates.

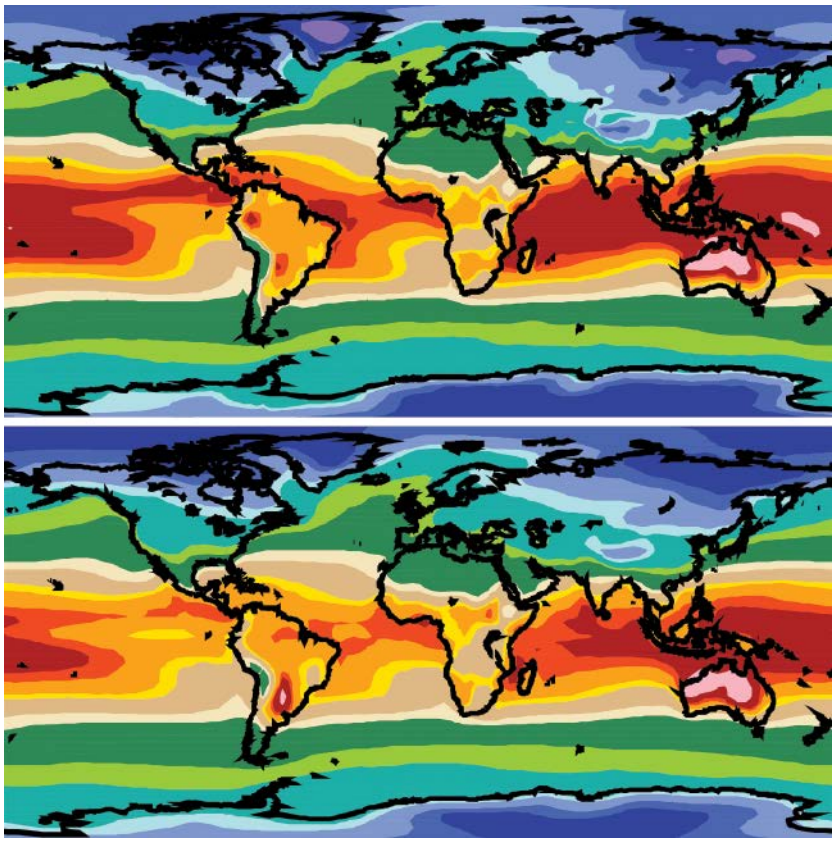
Climate model developers and those who use these models benefit from sharing information with each other. Both groups require access to the best available data and rely on open-source software tools designed to facilitate the analysis of climate data.

Computer simulation of Hurricane Sandy's path and intensity on 29 October, 2012, a day before landfall. At this point, Sandy was a Category 2 superstorm nearly 1500 kilometers wide.

William Putman, NASA Goddard Space Flight Center and NASA Center for Climate Simulation

Developers benefit the most from comparisons of their models with observations and other models when the results of such analysis can be made quickly available.

Here we introduce a new climate model evaluation package that quantifies differences between observations and simulations contributed to the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP). This package is designed to make an increasingly diverse suite of summary statistics more accessible to modelers and researchers.



Peter J. Gleckler/LLNL

(top) Observed and (bottom) simulated seasonal mean (December–January–February) 2-meter surface air temperature data. The observational estimate is taken from surface instrument records. The model result is an ensemble average of results from more than 20 climate models that were contributed to the Coupled Model Intercomparison Project.

The Coupled Model Intercomparison Project

Model intercomparison projects (MIPs) provide an effective framework for organizing numerical experimentation and enabling researchers to contribute to the analysis of model behavior. To improve our understanding of climate variability and change, CMIP coordinates a host of scientifically focused subprojects that address specific processes or phenomena, including clouds, paleoclimates, and climate sensitivity [*Taylor et al.*, 2012; *Meehl et al.*, 2014; *Eyring et al.*, 2015]. The results from CMIP are vast, of petabyte scale, with simulations contributed by tens of modeling groups around the globe.

By adopting a common set of conventions and procedures, CMIP provides opportunities for a broad community of researchers to readily examine model results and compare them to observations. The success of this project has been directly responsible for enhancing the pace of climate research, resulting in hundreds of publications and a multimodel perspective of climate that has proven invaluable for national and international climate assessments.

Metrics Package Aids Accessibility

As a step toward making succinct performance summaries from CMIP more accessible, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at Lawrence Livermore National Laboratory (http://www-pcmdi.llnl.gov) has developed an analysis package that is now available.

The PCMDI Metrics Package (PMP) leverages the vast CMIP data archive and uses common statistical error measures to compare results from climate model simulations to observations. The current release includes well-established large- to global-scale mean climatological performance metrics. It consists of four components: analysis software, an observationally based collection of global or near-global observations, a database of performance metrics computed from all models contributing to CMIP, and usage documentation.

PMP [*Doutriaux et al.*, 2015] uses the Python programming language and Ultrascale Visualization Climate Data Analysis Tools (UV-CDAT) [*Williams*, 2014; *Williams et al.*, 2016], a powerful software tool kit that provides cutting-edge diagnostic and visualization capabilities. PMP is designed to enable potential users unfamiliar with Python and UV-CDAT to test their own models by leveraging the considerable CMIP infrastructure. Users with some Python experience will have access to a wide range of analysis capabilities.

PMP enables users to synthesize model performance characteristics from dozens of maps and zonal average plots. The well-established quantitative tests of the seasonal cycle in the current release do not directly relate to the reliability of model projections but do represent important large-scale climatological features evident in observations [*Flato et al.*, 2013]. Modelers often consider information of this kind along with numerous other diagnostics, which they combine with expert judgment to help decide on a new model version among multiple candidates.

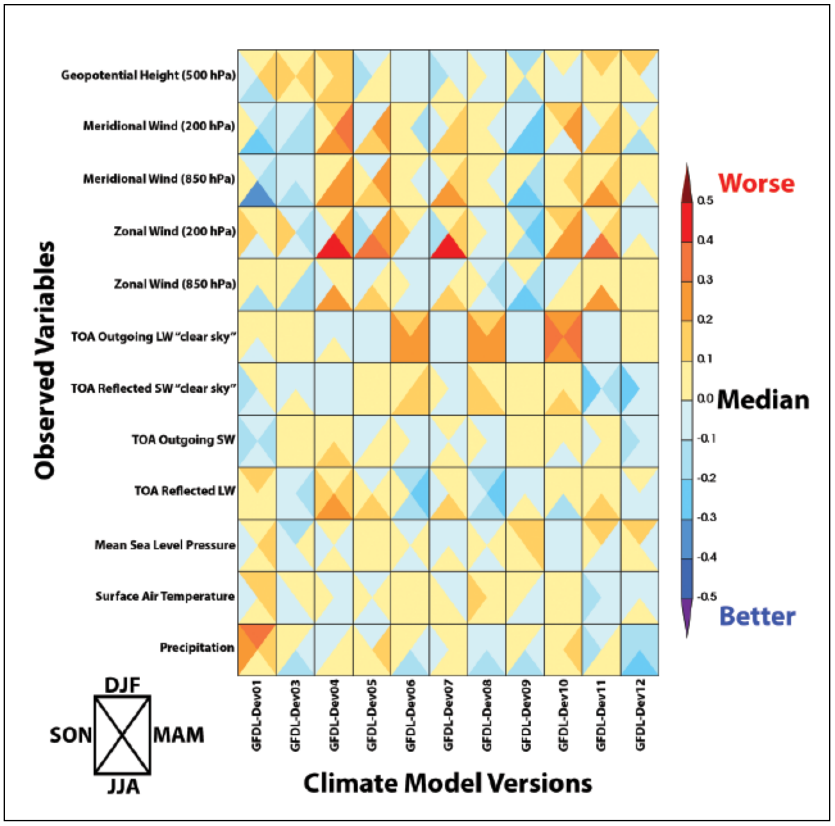
CMIP as a Model Development Tool

By the time research results are published—often many months or even years after CMIP output is generated and

becomes available—most model developers are already working on newer model versions that supersede the previous CMIP contribution. Modelers would benefit more directly from participation in CMIP if during the model development process the merits and shortcomings of their model relative to other state-of-the-science models were immediately apparent. The PMP database, when it is installed locally, enables modeling groups to rapidly compare their current model versions with CMIP models rather than await feedback from the external analysis community. This information can help identify deficiencies in a model, which can be useful in setting priorities for further model development work.

Modeling groups have already shown interest in PMP's ability to compare multiple versions of a model under development as part of its evaluation procedure. Figure 1 provides an example of how results from PMP can be used to summarize the relative merits and shortcomings of different configurations of the same atmospheric model run with prescribed sea surface temperatures and sea ice (the protocol of the Atmospheric Model Intercomparison Project (AMIP)).

Users can tailor the PMP "quick-look" results like Figure 1 to compare various characteristics of their model versions. For example, contrasting the development improvements or setbacks from different model versions in relation to the distribution of structural errors in the CMIP multimodel ensemble can provide an objective assessment as to whether model performance changes are significant. Making such objective summaries routine will aid the development process and help modelers ensure that they do not overlook any hidden degradation in model performance during development.



Erik Mason/GFDL

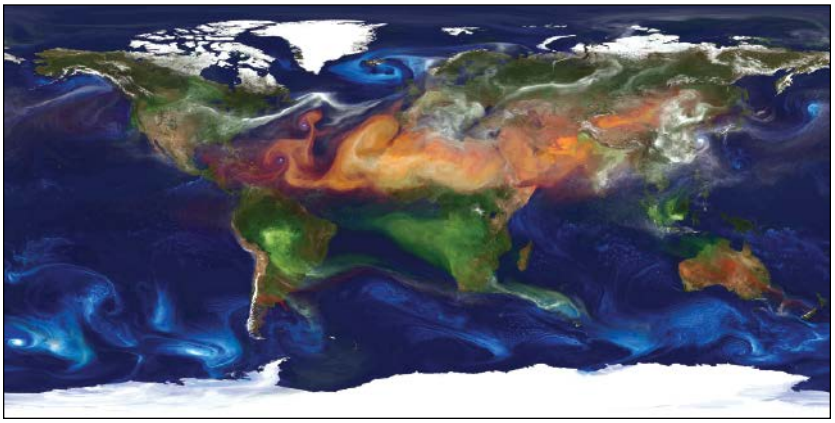
*Fig. 1. The Coupled Model Intercomparison Project Phase 5 (CMIP5) facilitates the comparison of results from various climate models. Shown here are relative error measures of different developmental tests of the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) model. Results are based on the global seasonal cycle climatology (1980–2005) computed from Atmospheric Model Intercomparison Project (AMIP) experiments. Rows and columns represent individual variables and models, respectively. The error measure is a spatial root-mean-square error (RMSE) that treats each variable separately. The color scale portrays this RMSE as a relative error by normalizing the result by the median error of all model results [*Gleckler et al., *2008]. For example, a value of 0.20 indicates that a model's RMSE is 20% larger than the median error for that variable across all simulations in the figure, whereas a value of –0.20 means the error is 20% smaller than the median error. The four triangles in each grid square show the relative error with respect to the four seasons (in clockwise order, with December–January–February (DJF) at the top; MAM = March–April–May, JJA = June–July–August, and SON = September–October–November). The reference data sets are the default satellite and reanalysis data sets identified by* Flato et al. *[2013]. hPa=hectopascals, TOA = top of atmosphere, SW = shortwave, LW = longwave.*

Routine CMIP Evaluation Made More Accessible

Future phases of CMIP [*Meehl et al.*, 2014; *Eyring et al.*, 2015] will call for a small ongoing set of experiments that will be revisited each time a new model version is released. Included among these benchmark experiments, which are referred to as the CMIP DECK (Diagnostic, Evaluation and Characterization of Klima; *Klima* is German for climate), is an AMIP run and a coupled (atmosphere-ocean-land-ice) model preindustrial control run with no external forcings. (External forcings are climate factors that are not simulated but included in some experiments as a time-varying constraining influence based on such data as volcanic eruptions, man-made aerosols, and increasing atmospheric carbon dioxide.) A historically forced coupled run is also proposed as an additional benchmark experiment, although the external forcings applied to these runs are likely to evolve across CMIP generations.

The expectation of these benchmark experiments (DECK and historical) is that they will encourage increased emphasis on developing diagnostic capabilities that can be used to systematically evaluate model performance. Because PCMDI's metrics package relies on the data conventions and standards used in CMIP, there is some assurance that it will be suitable and useful not only

during the current phase of CMIP but also indefinitely into the future.



William Putman, NASA Goddard Space Flight Center and NASA Center for Climate Simulation

A modeling run on NASA's Discover supercomputer maps global aerosols at a 10-kilometer resolution. Dust (red) rises from land surfaces, sea salt spray (light blue) swirls inside cyclones, smoke (green) rises from fires, and volcanoes and fossil fuel burning emit sulfate particles (white).

Current and Future Releases of PMP

Version 1.1 of PCMDI's Metrics Package (PMPv1.1) is publicly available (see http://bit.ly/PCMDI-metrics), with functionality that is currently designed to serve modeling groups or individuals performing simulations. It provides well-established model climatology comparisons with observations, including the following:

- area-weighted statistics: bias, pattern correlation, variance, centered root-mean-square difference, and mean absolute error
- results for global and tropical domains, the extratropics of both hemispheres, departures from the zonal mean, and land- and ocean-only domains
- multiple observationally based estimates of each field tested, including top-of-the-atmosphere and surface radiative fluxes and cloud radiative effects, precipitation, precipitable water, sea surface and 2-meter temperature, mean sea level pressure, surface air wind (10 meters), temperature (2 meters), humidity (2 meters), upper air temperature, winds, and geopotential height

In addition, metrics for the El Niño–Southern Oscillation recommended by the Climate and Ocean: Variability, Predictability, and Change (CLIVAR) Pacific Basin Panel are available in the PMP development repository.

Community users of PMP can develop and include additional tests of model behavior and work with the PCMDI team to integrate these into the package. Future releases will include summary statistics for sea ice distribution, land surface vegetation characteristics (in collaboration with the International Land Model Benchmarking (ILAMB) project), three-dimensional structure of ocean temperature and salinity, monsoon onset and withdrawal, the diurnal cycle of precipitation, major modes of climate variability, and selected "emergent constraints" [*Flato et al.*, 2013].

The results from CMIP are on the petabyte scale, with simulations contributed by tens of modeling groups around the globe.

Anyone interested in using PMP should contact the development team (pcmdi-metrics@llnl.gov) for information on the latest functionality and installation procedures, which are advancing rapidly. As we embark on developing PMP as a community-based capability, we would like to hear from anyone interested in working with us to include an increasingly diverse set of performance metrics that can be used for systematic evaluation of the CMIP DECK and other simulations.

Acknowledgments

The work from Lawrence Livermore National Laboratory is a contribution to the Regional and Global Climate Modeling Program, Climate and Environmental Sciences Division, Office of Science, U.S. Department of Energy under contract DE-AC52-07NA27344. We are grateful to our colleagues at the Geophysical Fluid Dynamics Laboratory, Institut Pierre-Simon Laplace, Commonwealth Scientific and Industrial Research Organisation, and National Energy Research Scientific Computing Center who have tested PMP and provided invaluable feedback for its improvement.

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Villages Must Recalibrate Time to Survive in the Pamir Mountains

Karim-Aly Kassam

Snow-covered peaks of the Pamir Mountains, known as "the Roof of the World," which tower as high as 7495 meters.

The calendar has stopped working for the people of the Pamir—the stunning, stark mountain range straddling the modern-day borders of Afghanistan and Tajikistan.

A shifting climate is disrupting not only their subsistence farming and herding but also their unique way of tracking time. Whereas the Gregorian calendar marks a year by 365 days spread across 12 months, Pamiri calendars are driven by observed cues in the environment spread across a calendar of the human body (see http://bit.ly/Body-Calendar). Local timekeepers name each new seasonal development after a part of the body, beginning with the toenail, then moving upward to the shin, the thigh, the intestines, the heart, and so on, until reaching the head. Arrival at the head coincides with the end of spring and a pause in counting. When the first cue of summer is observed, the counting sequence restarts, but this time from the head downward. Timekeepers rely on natural events—the nascence of a flower, arrival of a migratory bird, movement of fish, breakup of lake ice—as the indicators of seasonal change, not simply the number of days since significant positions of the Sun, Moon, and stars.

For centuries, this indigenous timekeeping strategy has offered local villagers an intuitive context for scheduling day-to-day life, from when to plow and seed to the timing of festivals and other events at the heart of Pamiri society. In recent years, however, climate change coupled with political instability has begun to disrupt the Pamir landscape, throwing these traditional ecological calendars out of sequence—and in need of recalibration.

"In climate change, there are two primary approaches: mitigate or adapt," said Karim-Aly Kassam, a professor of environmental and indigenous studies at Cornell University who has long worked in the Pamir region (see http://bit.ly/K-AK). For the people of the Pamir, "given that they are not the primary contributors to the causes of anthropogenic climate change, there's nothing significant they can do to mitigate. So they have to adapt."

To help them do so, Kassam has partnered with the Thriving Earth Exchange (TEX) program of AGU and the Massachusetts Institute of Technology Climate CoLab to find ways to reconcile the traditional timekeeping of the Pamiri with the modern reality of a changing world (see http://bit.ly/TEX-Kassam-Pamir). TEX brings together scientists and communities facing environmental challenges related to natural hazards, natural resources, or climate change to work to find solutions. The recalibration initiative came from the Pamiri people themselves, who reached out to Kassam for help to reconnect with their heritage of traditional ecological calendars and to adapt to the shifting baselines of climate change.

A Nexus of Change

The collaboration organized by Kassam expects to launch several projects this year to tackle the recalibration. In the meantime, the Pamiri live with a growing sense of unease.

Aloft at 2000 to 3500 meters in elevation, the villages of the Pamir are at the front lines of climate change. As glaciers and snowpack melt more quickly and spring rains become more intense, locals have reported increasing

water levels in rivers and lakes. Changes in water and temperature patterns have left villages scrambling to meet earlier starts to plowing seasons and to find alternative crops to grow in low-elevation areas where certain fruits no longer thrive or to take advantage of a newfound ability to grow wheat at higher elevations.

Until recent years, villagers could count on a local leader, a *hisobdon*, to track seasonal cues such as leaf budding as the first sign of spring. By counting the number of days until the next cue, the *hisobdon* would track the progression of time and season. With those reliable patterns breaking down, the effects differ among villages and valleys, but the shared psychological impact is one of anxiety: the inability to anticipate change and plan for each season, Kassam said. This breakdown is particularly debilitating for the people of the Pamir because of their reliance on environmental cues for planning agricultural and social routines.

Kassam is outspoken about the ethical imperative to work with communities like those in the Pamir. Although rural communities in alpine and polar regions contribute little to climate change, they are among the first to feel its effects, he noted—a consequence, in part, of living under already extreme conditions.

Three-Pronged Approach

Seeking additional resources and collaborators for recalibrating the Pamiri calendar, Kassam and his partner organizations held a research proposal contest. Originally expecting to select just one project, they decided instead to unite three winning proposals into one collective effort.

The projects are expected to begin in mid-2016. Working with local academic and village partners, one team will recalibrate Pamiri body calendars with updated environmental data (see http://bit.ly/recalibration). Another will try to apply the Pamiri calendar to water and drought forecasts (see http://bit.ly/drought_Pamir). The third team will conduct a biodiversity and phenology survey to help reconnect Pamiri calendars with seasonal and local shifts in flora and fauna (see http://bit.ly/Biodiversity-Pamir).

"Each [contest] winner had one aspect to it," Kassam said. "In a true 'wicked problem' approach, we said to them, 'We'd all win if you work with someone else!'" However, any effective plan must ground its strategy in the local ecological and cultural context in which the Pamiri people live, he added: "It has to be cognizant of their reality."

In March 2016, Kassam's research team received an additional 1.2 million euros from the Belmont Forum, a collaboration of funders of global environmental change research, to conduct further studies on ecological calendars in the Pamir Mountains of Afghanistan, China, Tajikistan, and Kyrgyzstan, in collaboration with Chinese, German, and Italian scholars.

Integrating Cultural Context into Climate Conversations

Kassam is keen to point out that this culturally grounded approach is just as relevant for climate change adaptation in the United States as it is for the Pamir Mountains. Working with people and communities—together in conversation and using their place-based knowledge—offers the best chance for successful climate adaptation solutions. On another traditional ecological calendar project with colleagues at Cornell, Kassam is working in collaboration with Native American communities on the Standing Rock Reservation in North and South Dakota.

"With wicked problems, scientific expertise is not enough; a diversity of experiences matters and is highly relevant when seeking solutions," Kassam said. "The AGU audience is central to this conversation. They are important, and they are essential. But they are not the only ones. We still need place-based knowledge. We need to do it together."

Wirow	Hairline
Pexhirni	Head
Tsem	Eye
Ghirjh	Ear
Nedz	Nose
Labi dandirn	Mouth and teeth
Birn	Beard
Gharth	Throat
Fetsak	Shoulder
Bijujh	Armpit
Sina	Chest
Zorth paywand	Heart vasculature
Zorth parvin	Pericardium
Zorth	Heart
Perz	Ribs
Darmun	Intestines
Mamari pas	Anus
Mamari pesh	Penis
Kordafson	Thigh
Zirn	Knee
Khambi zonu	Back of knee
Narmai po	Calf
Ling	Shin
Shurchak	Ankle
Puxhti po	Top of foot
Nokhun	Toenail

Art by Hakim Zavkibekov. From Kassam et al., 2011, doi:10.1163/187471611X600369.

In this figure depicting a Pamiri calendar of the human body, each body part provides a mnemonic that correlates with environmental cues. The cues also regulate timing for villagers regarding their health and social life.

By **Ben Young Landis,** Freelance Science Communicator/Contributing Writer for Creative Science Writing and the Thriving Earth Exchange; email: ben@cr8xt.com

Share Your Science with Teachers and the Public at Fall Meeting

AGU members advance and disseminate Earth and space science knowledge. They affiliate themselves with an AGU section or focus group that shares their interests and fosters scientific discussion and collaboration with other scientists. Wonderful opportunities to share knowledge more broadly—with children, parents, and teachers—await members of these sections and focus groups at the upcoming 2016 Fall Meeting. Exploration Station offers a range of family-friendly science exhibits and hands-on activities that give families the opportunity to interact with science and education professionals (see http://bit.ly/Exp-Station). The Geophysical Information for Teachers (GIFT) Workshop enables educators to learn about the latest Earth and space science research directly from scientists as well as from classroom resources designed to inspire a passion for science in students (see http://bit.ly/Geo-Info-4-Tchrs).

Karna Kurata

Visitors to Exploration Station try out virtual reality headsets during the 2015 Fall Meeting.

Exploration Station

Exploration Station draws Fall Meeting attendees and a public audience, too. Members of AGU's sections and focus groups volunteer to create and manage exhibits for families. Past Exploration Station exhibits have presented a variety of fun activities for children, including a planetarium, virtual reality headsets, and stomp rockets. Members of the Space Physics and Aeronomy section have driven AGU's member engagement, having offered the majority of exhibits in Exploration Station's early years and continuing to participate today. The number of sections and focus groups involved in Exploration Station exhibits has steadily increased in the past 6 years, from six in 2010 to 15 last year. In 2015, members of AGU's various sections and focus groups teamed up to create an unforgettable experience for children and their families, drawing more than 700 people to the event. If you are interested in becoming an exhibitor and sharing your love of science with children, please read our FAQ (http://bit.ly/Exp-Station-FAQ).

GIFT Workshop

Members of AGU's sections and focus groups also actively contribute to the GIFT Workshop at Fall Meeting. Scientists can pair up with an expert educator and share their science with K–12 teachers and informal educators. In 2015, 14 members from eight different sections and focus groups presented on a variety of topics, ranging from NASA's Kepler Mission to the science of fracking. In previous years, the GIFT Workshop featured presenters from 6–10 different sections and focus groups.

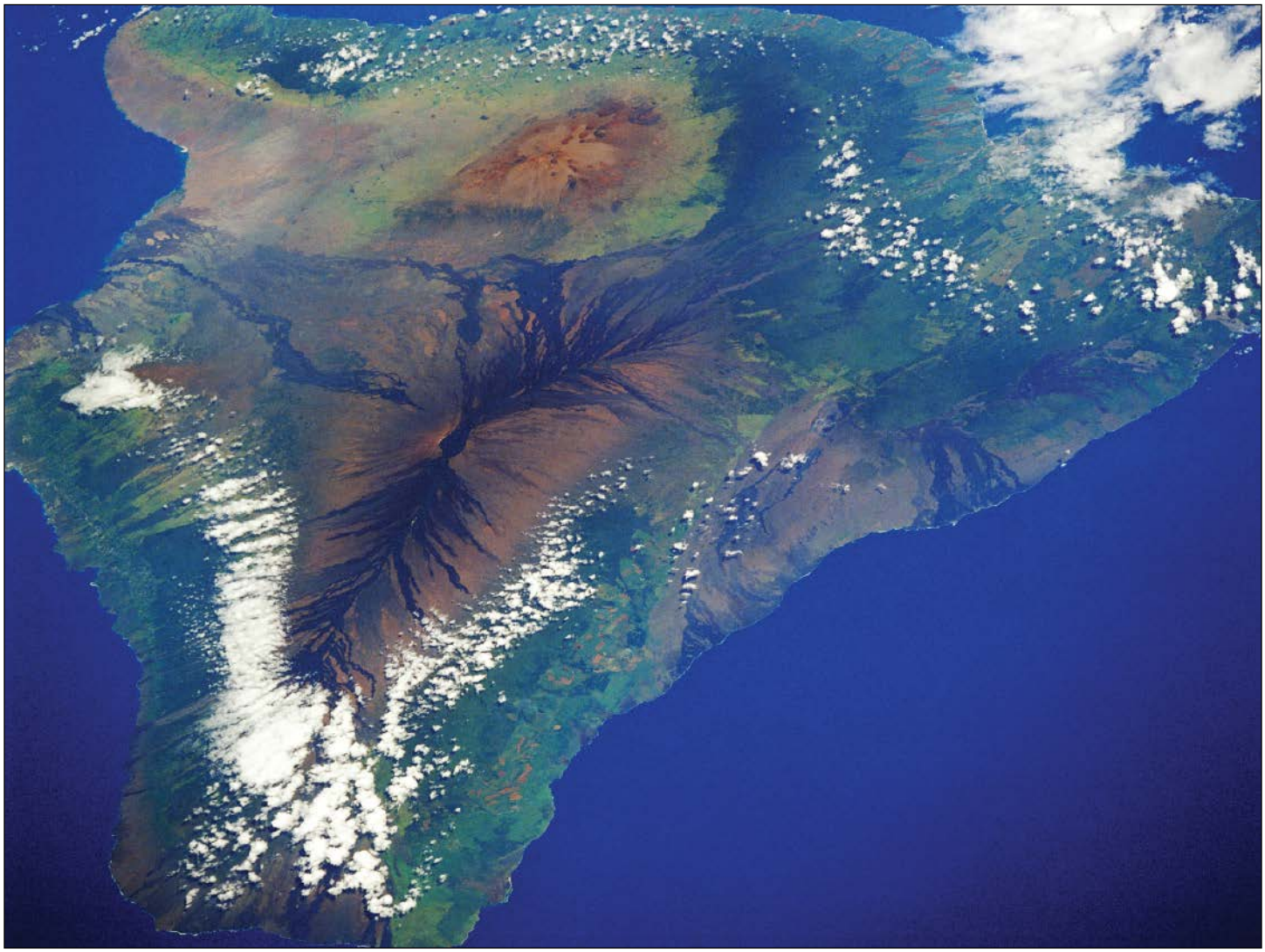
The number of sections and focus groups involved in Exploration Station exhibits has steadily increased in the past 6 years, from six in 2010 to 15 last year.

Get Involved

Exploration Station and the GIFT Workshop grow larger each year. AGU welcomes members who would like to get involved and share their love for Earth and space science. Members who share their time and knowledge at these programs empower our educators and inspire a love for learning in our future scientists. As one 2015 GIFT teacher said, "It is so wonderful to be able to attend a [professional development workshop] with talented presenters, a supportive community, and also be able to go across the street for high level scientific presentations." Exploration Station and the GIFT Workshop offer opportunities for science professionals, educators, and families to share in the joy of science learning. If you would like to share your love of science with others or see your science taught in classrooms, please contact exploration-station@agu.org or Pranoti Asher (pasher@agu.org).

By **Tess Reardon,** AGU Education Intern; email: treardon@agu.org

A Hole in Earth's Surface



NASA

The deep seismic activity on the island of Hawaii can be explained by the weight of the volcanoes atop the Earth below.

Hawaii is one of the most seismically hazardous locations in the United States; the island has been rocked by strong earthquakes with magnitudes of up to 7.9. These earthquakes occur when strain is released in the lithosphere—the outer portion of Earth's crust—beneath and next to the island. This strain is caused by the bending of the lithosphere under the enormous load of Hawaii's volcanoes. As the volcanoes grow and add more weight onto the lithosphere, the crust flexes downward, away from the volcanoes. The downward flexion, in turn, causes the lithosphere close to the volcanoes to flex upward. Ultimately, when the lithosphere stops flexing, the accumulated strain is released in the form of earthquakes.

In a new study, *Klein* proposes that the flexed lithosphere beneath Hawaii, coupled with the fact that the lithospheric plate beneath the island appears to be broken—it curves downward with a central depression—explains the region's heightened seismicity. The resulting plate flexure forms a doughnut hole shape right underneath the island. The focal hole in the center lies approximately between Mauna Loa, Earth's largest active volcano, and Mauna Kea, a dormant volcano whose peak is at the highest point of Hawaii.

The author used data taken from seismic stations around the island to understand the stress fields and focal mechanisms, which describe the slip that causes earthquakes and the orientation of the fault on which those quakes occur. The seismic data give valuable information about the orientation of the stress field and the pressure and tension axes for each earthquake.

By analyzing the seismic data, the author saw that the pressure axes of several earthquakes scattered through the island radiated from the center of the hole in the lithosphere. These radial patterns, according to the author, suggest that the downward-flexing lithosphere surrounds a weak region at its center. (*Journal of Geophysical Research: Solid Earth*, doi:10.1002/2015JB012746, 2016) **—Wudan Yan, Freelance Writer**

Ionospheric Waves Linked to Polar Atmospheric Dynamics

The ionosphere is one of the most fascinating parts of Earth's atmosphere. Formed when solar radiation hits atoms and molecules in the upper atmosphere, stripping their electrons off to produce a plasma, the ionosphere extends from about 64 to 966 kilometers above the surface of Earth.

As a result of the Sun's influence, the strength or weakness of the ionosphere depends heavily on time of day as well as time of year. The ionosphere on the dayside of Earth, for example, is much more heavily ionized than the nightside ionosphere. Similarly, in the wintertime, when solar radiation is significantly weaker due to the tilt of Earth's axis, there are fewer charged particles in the ionosphere than during the summertime.

In the fall and winter, scientists frequently observe wavelike disturbances in the ionosphere traveling from higher latitudes toward the equator. These waves are characterized by enhancements and depletions in the density of electrons in the ionosphere. Here *Frissell et al.* investigate what causes these wavelike disturbances. Some previous studies have suggested that they are caused by space weather activity (such as the aurora), whereas others suggest that the source of the waves is internal to Earth's atmosphere.

Using newly available Super Dual Auroral Radar Network observations, the authors discovered that the entire North American continent concurrently experiences enhancements and depletions of ionospheric wave activity lasting 2 to 4 weeks. No known space weather phenomenon routinely exhibits these multiweek time scales. However, the polar vortex, a huge cyclone of cold air situated above the North Pole, does. This discovery led the authors to focus research efforts on polar atmospheric dynamics.

After careful analysis, the researchers confirmed that no significant correlation between the ionospheric disturbances and space weather activity could be observed. However, the team found evidence for a statistically significant correlation between the ionospheric disturbances and polar vortex dynamics. This indicates that the dynamics internal to Earth's atmosphere, rather than influences external to Earth's atmosphere, are likely to be responsible for these disturbances. (*Journal of Geophysics Research: Space Physics*, doi:10.1002/2015JA022168, 2016)

—Kalman J. Knizhnik, Freelance Writer

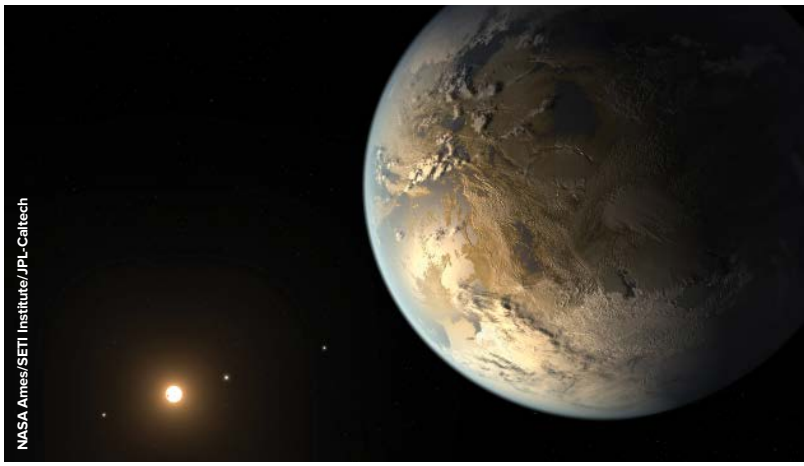
Becoming Habitable in the Habitable Zone

Day to day, plate tectonics may seem to have little to do with Earth's habitability. However, over time, interactions between our planet's climate, mantle, and core have created a suitable home for complex life. In a new review paper, *Foley and Driscoll* suggest that similar processes could set other rocky planets on very different trajectories, ultimately determining whether they could support life as we know it.

Cooler climates promote plate tectonics by keeping plate boundaries from fusing and by weakening the crust and outer mantle. In turn, plate tectonics help keep the climate temperate through carbon cycling. On Earth, cold slabs of rock subduct and sink deep into the mantle, drawing heat from the core. Long-term core cooling helps maintain Earth's magnetic field, which keeps the solar wind from stripping away the atmosphere.

The authors hypothesize that the climate-mantle-core connection determines whether a young, rocky planet will develop plate tectonics, a temperate climate, and a magnetic field—all of which are thought to be necessary for life. Initial atmospheric composition, timing of the onset of plate tectonics, and other factors can affect how climate-mantle-core dynamics unfold. This means that two similar planets might follow wildly different paths, even if they both reside in a solar system's habitable zone (where liquid water can exist on the surface).

The authors also suggest that interactions between the climate, mantle, and core might explain why Earth and Venus are so different, despite their similar sizes and composition: Venus's hot climate prevents plate tectonics, stifling a sustained magnetic field.



An artist's rendition of Kepler-186f, an Earth-sized planet in the habitable zone of a distant solar system. Little is known about its composition, but if it turns out to be rocky like Earth, it may be subject to climate-mantle-core interactions that determine whether it can actually sustain life.

Scientists don't yet know enough Venusian history to confirm the authors' hypothesis. Much more research is also needed to clarify connections between climate, mantle, and core for rocky planets in general, but a better understanding of these dynamics could help predict the likelihood of finding an Earth-like exoplanet. (*Geochemistry, Geophysics, Geosystems*, doi:10.1002/2015GC006210, 2016).

—Sarah Stanley, Freelance Writer

ATMOSPHERIC SCIENCE

Tenure Track Position

Washington State University, Department of Civil and Environmental Engineering and the Laboratory for Atmospheric Research (LAR) invite applications for a permanent 9-month tenure-track faculty position open at the assistant to associate professor level on the WSU Pullman campus with an effective start date in the window from January 1, 2017 to August 16, 2017. This position is part of WSU's priority to build a diverse faculty; thus, female and minority candidates are strongly encouraged to apply.

POSITION DESCRIPTION–Candidates are sought with expertise in the development, evaluation, and application of numerical air quality models related to air quality, atmospheric chemistry, and climate change at urban to regional scales. The successful applicant will be expected to help lead and grow the WSU AIRPACT air quality forecast system operations. The selected applicant will be expected to teach graduate and undergraduate air quality and environmental engineering courses, direct graduate student research, and develop a strong extramurally funded research program. The position requirements include: 1) expertise within the range of available urban to regional scale atmospheric chemistry models with applications to air quality, atmospheric chemistry, and/or climate change, 2) a record of research accomplishments as demonstrated by peer reviewed publications and/or extramural grants, 3) demonstrated ability to work with diverse, interdisciplinary teams in a collegial and collaborative manner, 4) a record of outreach, mentoring, or teaching to diverse student populations, and 5) an earned Ph.D. or equivalent degree in a relevant engineering or science field. In addition, experience using remote sensing and in situ observations to evaluate and improve models and participation in the design and implementation of field campaigns is desirable.

UNIVERSITY – Founded in 1890, Washington State University is a comprehensive research, land-grant institution with a total student enrollment of approximately 27,000. WSU has excellent faculty-friendly policies, including a partner accommodation program, and is the recipient of a 2008 National Science Foundation ADVANCE Institutional Transformation award to increase the recruitment, retention, and advancement of women faculty in science, technology, engineering and mathematics (STEM) disciplines (see www.ADVANCE.wsu.edu). The WSU Pullman campus is located in Pullman, WA, which is about 75 miles south of Spokane and is one of the largest residential universities in the West.

DEPARTMENT – The Department of Civil and Environmental Engineering is one of five departments within the Voiland College of Engineering and Architecture. The department has an active research program with approximately $7 million in external annual funding. The department maintains teaching loads in undergraduate and graduate instruction at attractive levels in order to allow time for research development and scholarly activities. Additional information about the department is available at http://www.ce.wsu.edu.

The Laboratory for Atmospheric Research is an air quality and climate change research group with a strong reputation for both measurement and modeling studies of air quality, atmospheric chemistry, and climate change (http://www.lar.wsu.edu). There are nine faculty members in LAR, and the group collaborates with WSU faculty and outside scientists across a broad range of topics. The LAR is a focal point for measurement and modeling studies supported through the Northwest Air Quality Environmental Science & Technology (NW-AIRQUEST) consortium, which includes active participation by federal, state, and local air quality agencies throughout the Northwest (http://lar.wsu.edu/nw-airquest/). In this role, LAR is responsible for the daily operation, maintenance and development of the AIRPACT regional air quality forecast system (http://lar.wsu.edu/airpact/).

APPLICATION PROCESS – Applicants should apply online at https://www.wsujobs.com/postings/24616 by submitting the following: a cover letter, a detailed resume, a statement of research and teaching interests, and a list of five references with contact information. Screening of candidates will begin September 1, 2016, but applications will be accepted until the position is filled.

WASHINGTON STATE UNIVERSITY IS AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION EDUCATOR AND EMPLOYER.

ENVIRONMENTAL SCIENCE

Faculty Positions in Geosciences and in Environmental Sciences

The Department of Earth and Planetary Sciences at Johns Hopkins University invites applications for multiple tenure-track or tenured faculty positions. The positions can be filled at the Assistant, Associate, or Full Professor level, starting as early as Fall 2016. The successful candidates are expected to develop internationally recognized and externally funded research programs, to help develop and participate in undergraduate and graduate teaching, and to supervise graduate student research. In the case of an appointment with tenure, the candidate must already be internationally recognized and have a demonstrated record of external research funding. A Ph.D. is required in the Earth Sciences or a related natural sciences discipline; post-doctoral experience is desirable. Applicants are sought for two focus areas:

Geosciences including low-temperature geochemistry and studies of the early Earth, cosmochemistry, geophysics and geodynamics, volcanology and igneous petrology. We are particularly interested in candidates whose research has synergies with our recent hires with expertise in sedimentary, metamorphic and tectonic processes, planetary geology, and planetary atmospheres.

Environmental Sciences including: natural resources (including water, metals, soils, and energy), ecology, critical zone science, marine sciences, cryospheric sciences, geomorphology, landscape hydrology, environmental change, air pollution, and, biogeochemistry. We are particularly interested in candidates whose research has synergies with our program in Global Environmental Change and Sustainability.

Opportunities exist for the successful candidate to forge research and teaching ties with other parts of the Johns Hopkins community that are active in the earth and environmental sciences, and sustainability. They include multiple engineering departments, Environmental Health Sciences at the School of Public Health, the Applied Physics Laboratory, and the cross-departmental Environment, Energy, Sustainability, and Health Institute. There are excellent opportunities for additional collaborations within the Baltimore-Washington region, including with the Carnegie Institution, the Smithsonian Institution, the U.S. Geological Survey, the University of Maryland, and NASA Goddard Space Flight Center.

Applications must be submitted electronically using Interfolio http://apply.interfolio.com/34960, should indicate the relevant focus area and must include a cover letter, a curriculum vitae, statements of research and teaching interests, and the names and complete contact information of at least three references. Questions concerning submission of application materials should be directed to Kristen Heisey (kgaines@jhu.edu). Other requests for information may be directed to Professor Sverjensky, Geosciences, Search Committee Chair (sver@jhu.edu) and/or Professor Waugh, Environmental Sciences Search Committee Chair (Waugh@jhu.edu). Review of the applications will begin immediately and will continue until the positions are filled. Applications received by 30 June, 2016 will receive full consideration.

Johns Hopkins University is committed to active recruitment of a diverse faculty and student body. The University is an Affirmative Action/Equal Opportunity Employer of women, minorities, protected veterans and individuals with disabilities and encourages applications from these and other protected group members. Consistent with the University's goals of achieving excellence in all areas, we will assess the comprehensive qualifications of each applicant.

HYDROLOGY

Faculty Cluster Hire in WATER

The University of California Irvine announces an interdisciplinary cluster hire of four faculty members to increase its capacity and world leadership in tackling the grand challenges related to water in urbanized environments, including water-related environmental and food security issues. Southern California is a mosaic of cities and open spaces whose history and future are inextricably tied to water, and whose experiences with water are paralleled by coastal metropolitan areas around the world facing population growth, development pressure, demands for ecosystem protection, and water scarcity. The cluster hire will build on UC Irvine's existing strengths in urban planning, public policy, hydrology, water resources, ecosystems, earth system science, and climate change and will be uniquely positioned and supported to grow new multidisciplinary collaborations across campus emphasizing new paradigms of sustainability and ecosystem resilience for metropolitan areas. We are seeking candidates whose research involves field studies, modeling and theory and, based on academic preparation and research interests, would fit into one of the following four Departmental positions:

Water resources: Tenured Associate or Full Professor in the Department of Civil and Environmental Engineering (http://engineering.uci.edu/dept/cee) with particular interest in candidates who integrate field studies, modeling and theory to advance understanding of water cycle dynamics in coupled human-natural systems.

Water and ecosystems: Tenured Associate Professor in the Department of Ecology and Evolutionary Biology (http://ecoevo.bio.uci.edu/) with particular interest in candidates who pursue predictive understanding of ecosystem processes and their response to climate and human pressures via theoretical, field work, and modeling approaches.

Water and food security: Tenure-track Assistant Professor in the Department of Earth System Science (http://www.ess.uci.edu) with particular interest in candidates with expertise and interest in understanding water at the intersection of optimizing food production and environmental sustainability in water-scarce environments.

Water and resource economics: Tenured Associate or Full Professor in the Department of Planning, Policy and Design (http://ppd.soceco.uci.edu/) with particular interest in candidates with expertise and interest in the area of environmental economics, natural capital, valuation of ecosystem services, urban planning, and public policy.

UCI has an exceptional array of field sites, open-space preserves, partner relationships, and research facilities that are strategically aligned in the context of geography, climatology, economic and social structures of southern California. Bringing faculty and students together around the theme of WATER offers a unique opportunity to create exceptional research capacity at UCI for addressing challenges at the water-food-energy nexus under increasing climate and human pressures. Applicants are encouraged to visit Departmental websites (shown above) to learn more about research strengths and programs. With this cluster hiring initiative, UCI aspires to identify exceptionally talented candidates who share our vision and will increase our capacity for world leadership.

Applicants are expected to have advanced degrees and publication records commensurate with appointment levels in the department of interest. Successful candidates will be expected to develop externally funded research programs, engage in both undergraduate and graduate education, and contribute their leadership and innovative thinking towards global prominence in water, cities, and the environment. Teaching opportunities will vary by Department and teaching qualifications will be a consideration for fit with the respective unit. Successful candidates will also be expected to contribute towards a campus-wide initiative to create more field-based (off-campus) student learning opportunities with the goal of increasing the number of students (especially underrepresented minority students) pursuing graduate degrees in water-related programs.

Applications should include a cover letter, a description of research interests illuminating potential to support the goals of the cluster hire, a description of teaching interests including ability to contribute to Departmental and interdisciplinary programs, a curriculum vitae, a statement describing commitment to diversity, and the names of at least four references. (References would not be contacted until the later stages of consideration, after consultation.)

To be considered for one of the four available positions, apply electronically at:

Department of Civil and Environmental Engineering: https://recruit.ap.uci.edu/apply/JPF03389

Department of Ecology and Evolutionary Biology: https://recruit.ap.uci.edu/apply/JPF03408

Department of Earth System Science: https://recruit.ap.uci.edu/apply/JPF03396

Department of Planning, Policy and Design: https://recruit.ap.uci.edu/apply/JPF03377

The University of California, Irvine is an Equal Opportunity/Affirmative Action Employer advancing inclusive excellence. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, age, protected veteran status, or other protected categories covered by the UC nondiscrimination policy.

INTERDISCIPLINARY

Planetary Interior Structure and Dynamics Scientist

The Jet Propulsion Laboratory (JPL), a Federally-Funded Research and Development Center operated by the California Institute of Technology for NASA, invites applications for a full-time position in interior structure and dynamics of planets and satellites. The applicant will join a broad-based team of scientists and engineers to advance JPL's Planetary Science research that excels in applying remote sensing data, in-situ measurements and state of the art models to planetary geophysics. Determining the interior structure and dynamics of planets, moons, and small objects is key to better understanding of the formation and differentiation of Solar System objects.

The scientific scope of interest for this position is broad, but candidates should have demonstrated expertise in one of the following areas:

Modeling of signal propagation in solid bodies and atmospheres, with applications, for example, to icy satellites, Mars, Venus, and giant planets.

Processing of geophysical data, in particular seismic signals, over a broad range of frequencies.

Material mechanical properties and their dependence on several parameters including pressure, temperature and forcing frequency

Modelling of planetary internal processes

Candidates should also be familiar with one or several of the following themes:

Modeling of interior structures (petrology, thermal structure) for terrestrial bodies and/or icy satellites.

Physics of multi-phase media (e.g., granular, partially molten material)

Atmospheric physics, e.g., atmospheric-surface coupling.

The selected applicant is expected to participate in or lead science definition and advancement of new science, technology, and mission proposals.

The applicant must have a PhD in Geology, Geophysics, Physics, or a related technical discipline. The applicant shall have an established reputation along with a broad knowledge of planetary measurement approaches and expertise in modeling and interpretation of the data for planetary science applications.

JPL/Caltech offers a competitive salary and impressive benefits, and provides research opportunities at the leading edge of Planetary Science. To view the full job description and apply, visit: http://Careerlaunch.jpl.nasa.gov/ (Job ID #2016-6584). Applications will be reviewed as they are received, and should include a curriculum vitae, a career statement with research objectives, and contact information for three professional references. JPL/Caltech is an equal opportunity/affirmative action employer.

Assistant/Associate/Full Professors - Physical and Biological Oceanography, Marine Geophysics/Geology, and Ocean Engineering

South University of Science and Technology of China

The school of oceanography at the South University of Science and Technology of China (SUSTC) invites applications for several tenure-track (or tenured) faculty positions at the ranks of Assistant, Associate, and Full Professor. Applicants must have earned Doctoral degrees in marine geophysics/geology, physical oceanography, biological oceanography, ocean engineering or closely related field. Successful applicants will be expected to establish a robust, externally funded research program and demonstrate a strong commitment to undergraduate and graduate teaching, student mentoring, and professional service. These positions will be open until filled.

SUSTC is a young university at Shenzhen in southern China since 2010 which is set to become a world-leading research university, to lead the higher education reform in China, to serve the needs of innovation-oriented national development and the needs of building Shenzhen into a modern, international and innovative metropolitan. These positions are created with a significant development to establish a vigorous research program in oceanography at SUSTC to serve the national call for China's important role in deep sea research and resource-oriented exploration in the world oceans.

To apply submit a cover letter, complete vitae with list of publications, and three names of references via http://talent.sustc.edu.cn/en/, or to Dr. Y. John Chen, Chair Professor at School of Oceanography, South University of Science and Technology of China, No 1088, Xueyuan Rd., Xili, Nanshan District, Shenzhen, Guangdong, China 518055.

JÜLICH
FORSCHUNGSZENTRUM

Forschungszentrum Jülich pursues cutting-edge interdisciplinary research on the pressing issues of our time. It helps to solve the grand challenges facing society in the fields of energy and environment as well as information and the brain. With more than 5,700 employees, Jülich – a member of the Helmholtz Association – is one of the large interdisciplinary research centres in Europe.

The Institute of Bio- and Geosciences – Agrosphere (IBG-3) conducts research to improve our understanding of biogeochemical and hydrological processes in terrestrial systems. Specific studies focus on environmental controls on biogeochemical cycling of elements, the analysis of exchange processes and nutrient dynamics in the soil-plant-atmosphere continuum. A combination of experiments, modelling and innovative observation technologies is used to bridge the gap between model, process and management scale. Its research contributes to the sustainable and resource-conserving use of soils and water and to the quantification of the effect of climate and land use change on terrestrial ecosystems. We offer a competent and interdisciplinary working environment, as well as an excellent framework in the areas of experiments and modelling.

The goal of the newly founded International Soil Modelling Consortium (ISMC) is to integrate and advance the various soil system modelling approaches and promote acquisition, standardization and provision of soil and terrestrial environmental data including model predictions. The consortium aims to provide a broad range of publicly accessible ecosystem services on both local and global scales in the context of: climate change, changes in land use, agricultural use of soils and terrestrial systems.
The ISMC will contribute to the development of a new generation of soil models and provide a knowledge platform for the integration of models and observation data and interfaces with complex climate, biosphere and terrestrial-based soil system models. In the context of these activities, the ISMC is looking for a coordinator and project manager for the organisation, further development and coordination of the consortium and for organising the joint research and development activities.

We are looking to recruit a

Research Scientist (f/m) International cooperation and project management: earth sciences, soils, modelling, ecosystem services

Your Job:

- Organising and coordinating activities between the partners and on behalf of the Scientific Committee of the ISMC, as well as preparing and agreeing contracts where necessary
- Identifying synergies between the partners and developing strategic research concepts together with the Scientific Committee
- Ensuring the accessibility of experimental and modelling data, including its amalgamation or linkages
- Making modelling software and modelling data available, as well as supporting ISMC scientists in the integration and global networking of this software
- Researching and establishing contacts for acquiring further strategic scientific partners and potential customers from the worlds of industry and private Business
- Supporting or applying for external funding to finance scientific projects and joint research projects between partners
- Heading the ISMC office, including the organisation of regular meetings of the Scientific Committee and Executive Board, (main) conferences and working group meetings, creating reports, handling publicity-related tasks including the Internet presence, issuing newsletters, annual reports etc.
- Developing concepts and establishing specialist seminars and summer schools for the scientific community and (agricultural) industrial companies in alternating international locations of the ISMC partners

Your Profile:

- Degree in natural sciences or engineering and a doctorate in a specialist area
- Preferably a track record of scientific and relevant publications
- Knowledge and experience in the area of modelling terrestrial systems
- Knowledge and practical experience in the management of (externally funded) research projects
- Experience in interacting with scientists, decision makers and the public
- Willingness to travel internationally
- Ability to cooperate in interdisciplinary and international working groups
- Very good organisational skills
- Excellent communication skills, especially in English (spoken & written)

Our Offer:

- international, interdisciplinary working environment on an attractive research campus, ideally situated between the cities of Cologne, Düsseldorf and Aachen
- limited for 2 years with possible longer-term prospects
- Salary and social benefits in conformity with the provisions of the Collective Agreement for the Civil Service (TVöD)

We also welcome applications from disabled persons.

We look forward to receiving your application, preferably via our online recruitment system, until 19.06.2016, quoting the **reference number 2016-096**.

Contact:
Anja Schurf
Phone: 02461 61-9700
fz-jueliche.de

Postcards from the Field

Dear Everyone,

Greetings from the upper stretches of the Oman ophiolite. The pillow basalts in Wadi Jizzi, here, took my breath away. A wonder of the GeoWorld. Wish you were here!

Simon Redfern, Department of Earth Sciences, University of Cambridge.

View more postcards at *http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.*